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PROPERTIES OF ENGINEERING MATERIALS AT  
EXTREME SUBZERO TEMPERATURES WITH  
SUPPLEMENTARY INFORMATION ON LIQUID  
HYDROGEN

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# CONVAIR | ASTRONAUTICS

CONVAIR DIVISION OF GENERAL DYNAMICS CORPORATION

AD830091

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EXTREME SUBZERO TEMPERATURES WITH  
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GENERAL DYNAMICS  
ASTRONAUTICS

FEB 2 1962

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## REVISIONS

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FOREWARD

This report was prepared for the purpose of supplying design criteria relating to the physical and mechanical properties of engineering materials at extreme subzero temperatures. It is intended to extend and complement Report No. AA-M-23, entitled "Properties of Materials at Liquid Oxygen and Liquid Hydrogen Temperatures", by A. Hurlich, by presenting data obtained in the interim (15 March 1957 to 1 December 1958). In addition, this report presents some supplementary data relating to liquid hydrogen.

Because this report is concerned primarily with materials suitable for use in missiles and space vehicles, primary attention has been focused on high strength, light weight materials such as austenitic stainless steels, titanium and aluminum alloys, certain plastics, and light weight insulation materials.

The data contained in this report were obtained from Convair laboratory tests, the open literature, and private communication with both commercial and government laboratories. The cooperation of these laboratories is gratefully acknowledged.

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### SUMMARY

This report was prepared for the purpose of supplying physical and mechanical property data necessary for the specification of engineering materials in service applications at temperatures ranging down to  $-423^{\circ}\text{F}$  (the boiling point of hydrogen at atmospheric pressure). Since this report is primarily concerned with materials to be used in missiles and space craft, emphasis has been placed on those materials most suitable for this application, such as high strength, light weight alloys, and light weight plastic insulation. In addition, since fabrication problems often present design limitations, all available information on welded joints at low temperature are presented.

The data presented in this report were gathered from a wide variety of sources. Convair laboratory data, the open literature, and private communication with various commercial and government laboratories were the primary sources of information. Certain supplementary information relating to liquid hydrogen are presented in the appendix. These data have been found useful when specifying materials for use in this environment. Similar supplementary data pertaining to thermocouple e.m.f. at low temperature are included.

Because low temperature data are relatively difficult to obtain, many of the experimental points represent the results of only one or two tests. Thus, the data presented must be used with caution, and in some cases further testing is desirable to establish greater confidence levels. Although the data presented are believed to be accurate, the data apply only to the materials in the heat treated conditions as stated, and generalization from one sample to an alloy class, or extrapolations from one temperature to another are unwarranted.

The major conclusions are:

1. The fundamental nature of deformation and fracture at low temperature has not yet been elucidated. Therefore, generalization and extrapolation of existing data is not warranted.
2. The available body of low temperature data indicate that the most important factor in low temperature behavior is crystal structure.

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- a. Face centered cubic alloys generally retain their ductility and toughness at low temperature. They exhibit large increases in tensile strength and moderate increases in yield strength with decreasing temperature. Examples include austenitic stainless steel (300 series), aluminum, nickel, and copper alloys. Important exceptions occur such as the manganese austenitic steels. In addition, heat treatments which strengthen these alloys by precipitation of a second phase (i.e. age hardening) frequently cause embrittlement at low temperature. Examples include the age hardening aluminum alloys such as 7075, Inconel X, and K-Monel. Furthermore, the austenitic stainless steels, being thermodynamically unstable, tend to undergo embrittling phase reactions at low temperature. These examples show that generalizations are not valid, and that every alloy must be tested prior to use at low temperature.
  - b. Body-centered-cubic alloys, such as iron, tend to undergo a ductile to brittle transformation at low temperature which limits their utility. Although these alloys may exhibit large ductility as measured by elongation and reduction of area, their toughness as measured in impact tests is essentially zero, and they are, therefore, unsuited to low temperature service. Again, exceptions occur, such as tantalum and certain ordered structures.
  - c. The hexagonal-close-packed alloys, such as magnesium and titanium, are generally brittle at low temperature, but important exceptions occur, such as certain titanium alloys. These alloys must be tested in every case to establish their low temperature properties.
3. The alloys best suited for service at  $-423^{\circ}\text{F}$  in missile and space craft are primarily the austenitic stainless steels (300 series), aluminum and nickel base alloys, and possibly 6Al-4V titanium alloys. The steels must be tested to determine the conditions under which embrittlement occurs, especially in welded joints. The aluminum and nickel base alloys must be studied to determine to what extent, if any, second phases can be tolerated before excessive embrittlement occurs.

4. The most promising high strength alloys are 301 stainless steel and 5083 aluminum (which is actually a medium strength aluminum alloy), some nickel base alloys, and 6Al-4V titanium.
5. Due to embrittling reactions which may occur during welding, base metal property data should not be extrapolated to welded joints.
6. The physical property data show that large variations in thermal conductivity occur between these high strength alloys. Stainless steel and titanium have relatively low thermal conductivity, compared to that of aluminum, which is high.

The following recommendations are based on the shortcomings of available data:

1. Comprehensive welded joint information should be generated for those alloys exhibiting good low temperature properties.
2. The nature of second phase embrittlement should be investigated in age hardening alloys such as aluminum and nickel base alloys (e.g. 7075 and Inconel X).
3. Thermal conductivity data should be obtained for composite structures such as honeycomb.
4. Fundamental studies concerning flow and fracture should be conducted or otherwise supported.

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## DISCUSSION:

### Introduction

With the introduction of liquid hydrogen as a rocket fuel, the minimum temperature that engineering materials must endure has been lowered to  $-423^{\circ}\text{F}$ , as contrasted with the  $-296^{\circ}\text{F}$  encountered in liquid oxygen. The number of materials that retain appreciable toughness and ductility at this temperature is severely restricted, and when the additional requirements of high strength and low weight imposed by the airborne application are imposed, the useful materials are limited essentially to the austenitic stainless steels, aluminum, and nickel base alloys, and possibly the 6Al-4V titanium alloy. Even in these alloys, undesirable effects occur which must be controlled before the alloys can be safely used at  $-423^{\circ}\text{F}$ . The austenitic stainless steels, for example, may undergo embrittling phase reactions at low temperature. These reactions are especially troublesome in welded joints, and must be controlled by chemistry, heat treatment, etc. The aluminum and nickel base alloys are usually strengthened by age hardening heat treatments which introduce second phases into the metallic matrices. However, these second phases cause reductions in impact strength at low temperature. Consequently, these alloys cannot be used in their highest strength condition, but a compromise must be made between tensile strength and impact strength. The 6Al-4V titanium alloy has exhibited useful impact strength at  $-320^{\circ}\text{F}$  in limited tests; but further evaluation is required for this alloy before it can be used at  $-423^{\circ}\text{F}$ .

Since welding is an important phase of missile fabrication, the available properties of welded joints have been presented in this report. Due to the complex nature of the welding process (i.e. the complex thermal history of the joint combined with the metallurgical variables between the weld and parent metal) data of this type are required before behavior of a welded structure can be determined at  $-423^{\circ}\text{F}$ .

The mechanical property data presented were generally obtained from commercial equipment modified for operation at low temperature. Such a modification of a tensile machine is shown in Figure 1. Samples were immersed in cryogenic fluids during fatigue tests and just prior to impact tests.

A number of reports are available which present low temperature properties data relating to a variety of materials. This report differs from these in that only those materials suitable for missile applications are considered. An appendix relating to the properties of liquid hydrogen, thermocouple, e.m.f. and heat flow at  $-423^{\circ}\text{F}$  is included.

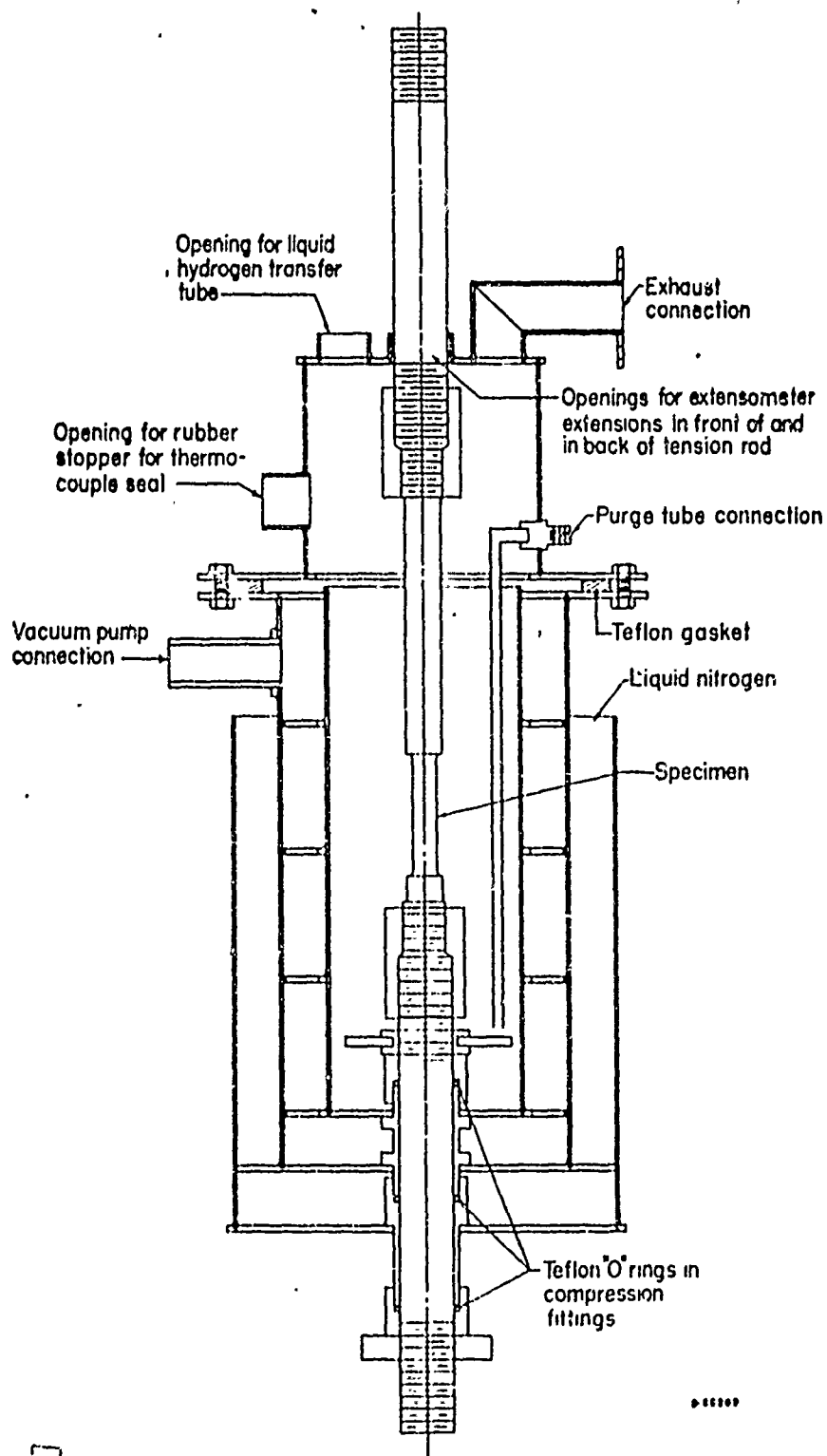


FIGURE 1. DRAWING OF LOW-TEMPERATURE CONTAINER USED  
 IN MAKING TENSILE TESTS AT  $-253^{\circ}\text{C}$  IN LIQUID  
 HYDROGEN - DATA FROM WADC REPORT 58-386

### DISCUSSION AND ANALYSIS:

This portion of the report considers the data available on various low temperature materials, and analyzes it in terms of reliability, significance, and general applicability.

**Stainless and High Alloy Steel** - The 300 series austenitic stainless steels have been the subject of many low temperature investigations because they retain excellent ductility and toughness at the lowest test temperatures attainable, as well as exhibiting good tensile strength. The mechanical properties of Types 301, 302, 303, 304, 310, 316, and 321, at low temperature are presented in Figures 2 through 13. Types 301, 302, 303, 316, 321, and 347 generally show large increases in tensile strength, moderate increases in yield strength, and moderate decreases in elongation and reduction of area with decreasing temperature. Type 310 exhibits an anomalous decrease in elongation at  $-423^{\circ}\text{F}$  which is unexplained, but indicates that caution should be employed when specifying it for use at  $-423^{\circ}\text{F}$ . Tables I and II present impact data (a measure of toughness) for these steels, which indicates good toughness at low temperature for all of the alloys tested. Young's Modulus (E) data are given in Table III. Figure 14 and Tables IV, V, and VI present tensile and impact data on welded joints at low temperature. Good strength and impact properties are retained in all alloys tested. Certain stainless steels (those containing more than .04% carbon without stabilizing elements such as titanium or columbium) are susceptible to embrittlement if held at temperatures of about  $1200^{\circ}\text{F}$ . Steels subjected to this temperature will be severely embrittled for all temperature applications, and must be annealed ( $1800^{\circ}\text{F}$  one hour) and quenched to remove the embrittling agents.

Table VII presents the results of a comprehensive research program conducted at  $-423^{\circ}\text{F}$ . Points of interest include the following:

1. In high nickel, high manganese alloys elongation increases at low temperature.
2. High nickel alloys have lower reduction of area at low temperature (by 50%), because the mode of deformation is much more uniform.
3. The Hadfield manganese steel is devoid of ductility at low temperature.
4. The 31% nickel steel showed a threefold increase in yield strength at low temperature.

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Table VIII and Figure 15 present further low temperature data on austenitic steels, and again the Hadfield manganese steel is seen to be brittle at low temperature. The reason for this embrittlement is not known at present, and therefore the manganese bearing austenitic steels (200 series) are not recommended for low temperature service. These steels represent a fertile field for fundamental research into the basic nature of plastic flow and brittle fracture.

Tables IX, X and XI present data comparing 301 and 301-N stainless steels. Both types show good mechanical properties in the base metal condition at low temperature. However, in the welded joint configuration, the 301-N undergoes an embrittling reaction at low temperature as is shown in the fatigue and tensile tests. The nature of this embrittlement is not understood, but it is suspected that the precipitation of chromium nitride during welding may be responsible.

Tables XII and XIII present data concerning the problem as to whether or not properties are permanently changed if a sample is cooled, held, and then reheated to room temperature. The data show that there is no permanent change unless an irreversible phase reaction occurs at low temperature. Table XII shows that significant changes occurred only in the AM350 and the 419 stainless steel. The AM350 undergoes an embrittling reaction at low temperature with resulting lowered impact strength at room temperature. The 419 stainless does not undergo an embrittling reaction, but instead exhibits a ductile to brittle transition at low temperature. This fact accounts for its low impact strength at low temperature. In Table XIII, the only stainless steels showing increased hardness, presumably due to phase reaction, are Type 321 and 12Cr-8Ni-2Mo. This increase is very small and would not eliminate these materials from low temperature service. Figures 16 and 17 and Tables XIV and XV show that 17-7PH and AM350 lose most of their ductility as measured by elongation and reduction of area between -320°F and -423°F. The impact data for AM350 in Table XV shows a continuous decrease with decreasing temperature, as expected. It is doubtful that either of these alloys will find use at -423°F.

Although the data in Table XVI were not obtained at low temperature, they show the increases in properties obtainable by rolling certain stainless steels at low temperature. The increase in properties is attributed to a phase reaction which occurs to a greater extent at low temperature. As a point of interest, this table also shows the effect of aging at 550°F for 24 hours, subsequent to rolling.

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Figures 19 and 20 have been included to indicate the mode of deformation at low temperature and to contrast these modes at ambient and low temperature. Type 302 and 303 stainless steel show the effects of phase reactions which occur with increasing deformation causing resultant hardening. The 310 alloy, because it contains more nickel, does not undergo this type of reaction and, therefore, shows a typical stress-strain curve at all temperatures. The 416 stainless is brittle at low temperature and, therefore, exhibits erratic stress-strain curves at low temperature.

Tables XVII and XVIII show the effects of low temperature on the properties of nickel steels, in both the base metal and welded joints. These tables show the powerful effect of nickel in preventing low temperature embrittlement.

The shortcomings of these data lie in the inadequate information relating to welded joints and 301 stainless cold rolled to extremely high strength levels. These are areas of primary significance in missile design, and these data should be generated as rapidly as possible.

**Nickel Base Alloys** - Nickel base alloys are attractive for low temperature applications because they are inherently stable and have good ductility at all temperatures. They have no tendency to become embrittled by phase reactions, as do certain stainless steels at low temperature. They also exhibit good tensile strength in the cold rolled state. It is an interesting fact that face centered cubic alloys generally exhibit good high temperature properties (i.e. creep strength). Since this structure is also associated with good ductility at low temperature, it happens that some "high temperature" alloys are also suitable for low temperature applications.

Figures 21 through 28 show that in general both the tensile and yield strengths increase moderately with decreasing temperature. Elongation and reduction of area remain high at low temperature and excellent toughness is also retained, as is shown in Table XIX. The cold worked alloys have less impact strength than do the annealed alloys, but still their toughness is good at the lowest temperature tested. Those nickel base alloys that depend on an age hardening reaction for higher strength, such as K-Monel, would be expected to have a lower impact strength at low temperature, and this expectation is confirmed in Table XIX.

The high temperature alloys listed in Table XX are age hardened and would be expected to have relatively poor low temperature properties, especially impact strength.

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The most promising alloys of this group for low temperature application are the nickel and cobalt base alloys cold rolled to high strength. No data exist for alloys of this type such as Haynes 25, R-235, etc. Data on welded joints is non-existent at low temperature and should be obtained as soon as possible. Further experimental work should also be done to determine the relation of second phase size and distribution (and hence strength) on the low temperature impact properties. This work is especially applicable to alloys such as K-Monel that can be formed in the soft condition and age hardened to suitable high strength levels.

**Aluminum Alloys** - The room temperature properties of those aluminum alloys recommended for low temperature service are given in Tables XXI through XXX, and the low temperature properties are presented in Figures 31 through 36 and Tables XXXI through XXXIV. Again, the tensile strength is seen to improve markedly and the yield strength slightly with decreasing temperature. The reason for this behavior is not completely understood at present and presents an interesting area of research.

The aluminum alloys suitable for low temperature service are the solid solution type, and therefore do not generate the higher strength characteristics of the age hardening alloys. These higher strength alloys, due to the precipitate which accounts for their strength, become somewhat embrittled at low temperature, especially in welded joints. Such a high strength alloy is shown in Figure 32.

Fatigue data on two aluminum alloys, 24S-T4 and 75S-T6, are given in Figures 35 and 36.

The limited welded joint data available, Table XXXI, show that the 5083 alloy retains full strength at low temperature.

**Titanium Alloys** - Titanium, belonging to the hexagonal close packed crystal structure, would normally be expected to be brittle at low temperature. However, some alloys, notably 6Al-4V, retain fairly good toughness at  $-320^{\circ}\text{F}$ . A large body of low temperature data have been gathered by Battelle Memorial Institute and are presented in Tables XXXV. Here the 6Al-4V alloy is seen to exhibit good toughness in a variety of samples. Further data obtained by Convair are presented in Tables XXXVI through XXXIX. These data confirm the toughness of the 6Al-4V alloy at  $-320^{\circ}\text{F}$ , and also show that RS-140 loses the major portion of its impact strength at  $-320^{\circ}\text{F}$ . The alloy B120VCA is seen to be brittle at low temperature and is not, therefore, suited for low temperature application.

Although only limited impact data are available at  $-423^{\circ}\text{F}$ , Figures 37 through 39 indicate notch sensitivity is developing between  $-320^{\circ}\text{F}$  and  $-423^{\circ}\text{F}$ . For this reason more data must be made available before these alloys could be recommended for service in liquid hydrogen.

**Magnesium Alloys** - Data on magnesium alloys at low temperature are limited, but those data available show that its ductility as measured by elongation and reduction of area decrease rapidly at low temperature. In general, its impact strength is low at room temperature and remains low at low temperature. For this reason it has not found many applications at low temperature.

**Copper Alloys** - Although copper alloys are not usually considered as missile materials due to their relatively low strength and high density, some data are included here because of the excellent low temperature properties of these alloys. Their excellent thermal and electrical properties combined with their ease of fabricability by soldering and brazing may gain them limited application. The data all show increasing tensile and yield strengths with decreasing temperature, and again the unexplained phenomena of increasing ductility with decreasing temperature is observed in all the alloys studied, except for the phosphor bronze.

**Low Alloy Steels** - All steels in this category undergo a ductile to brittle transformation slightly below room temperature. This transformation occurs over a temperature range that is dependent upon chemistry, heat treatment, grain size, etc. Several figures have been included (Figures 66 through 75) which illustrate this type of behavior, which makes this class of alloys unsuitable for low temperature service.

**Solders** - Extremely limited data on solders in Figure 77 and Table XL indicate that high lead solders retain good ductility and excellent toughness at  $-423^{\circ}\text{F}$ . Large amounts of tin in the solder lower impact strength and are, therefore, not recommended for low temperature service. A few tests indicate that indium solders may be promising for low temperature application.

**Plastics** - Mechanical test data on plastics are extremely meager at low temperature. Notched and unnotched data on a filled epoxy are given in Figure 80, and stress-strain curves for expanded polystyrene and expanded epoxy resins are given in Figures 78 and 79, respectively. Also see pages 153 and 154.

**Physical Properties** - Thermal conductivities for most pure metals and alloys have been determined over a range of temperatures down to  $-454^{\circ}\text{F}$ ,

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the boiling point of helium. The data are presented in Figures 83 through 97 and Tables XLII through XLVIII. Some data on thermal conductivities of plastics and insulation materials have been determined and are presented in Figures 98 through 101 and Tables XLIX through LI. Polystyrene foam (Styrofoam) is seen to be the best choice among solid foams, and furthermore, has adequate strength combined with low density. Better insulations may be had by filling evacuated spaces with powdered insulations which act as thermal radiation shields and yield extremely low conductivity.

Some mechanical property data on plastics are given in Figure 98 and Table L, along with specific heat, emissivity, and thermal expansion data for miscellaneous solids. Further thermal expansion data are presented in Tables LII through LIII and Figures 102 and 103.

Liquid Hydrogen and Miscellaneous Design Data - These data were included in this report to cover questions that frequently arise during materials selection for liquid hydrogen environment applications. The thermocouple e.m.f. data and heat flow calculations are useful to any experimentalist working in this field.

Hydrogen is distinguished by the occurrence of two molecular varieties which differ from each other in the nature of their nuclear spins. In the ortho configuration the spins are parallel, causing the molecule to be magnetic, while in the para form the spins are antiparallel and the molecule is nonmagnetic. The equilibrium ratio of ortho to para at room temperature is 75.0/25.0 ("normal" hydrogen) while at  $-423^{\circ}\text{F}$  the equilibrium ratio is 0.2/99.8.

If normal hydrogen is liquefied, the ortho to para conversion process will occur spontaneously with a liberation of heat which is of sufficient magnitude to cause large boil-off losses (20% per day). To avoid this boil-off loss, hydrogen is liquefied in a process involving catalyst which yields a product that is almost all para hydrogen. The significance of this to the missile engineer is simply that liquid hydrogen used as a rocket fuel must be in the para form to prevent large boil-off losses.

Data from NBS Report No. 5009, by  
Kropschot and Graham.

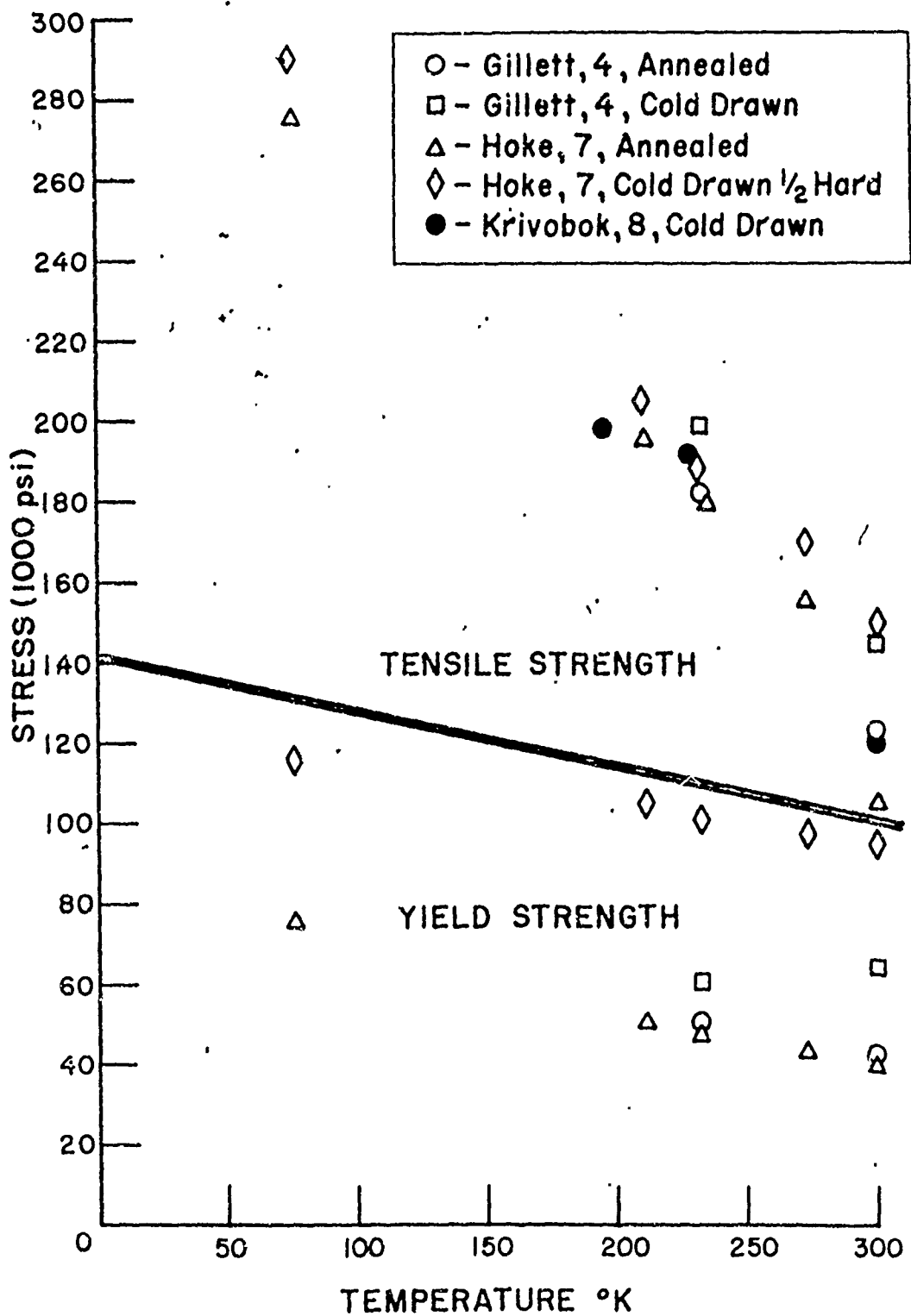


Figure 2. Tensile and yield strength of 301 stainless steel.

Data from NBS Report No. 5009,  
by Kronschof and Graham

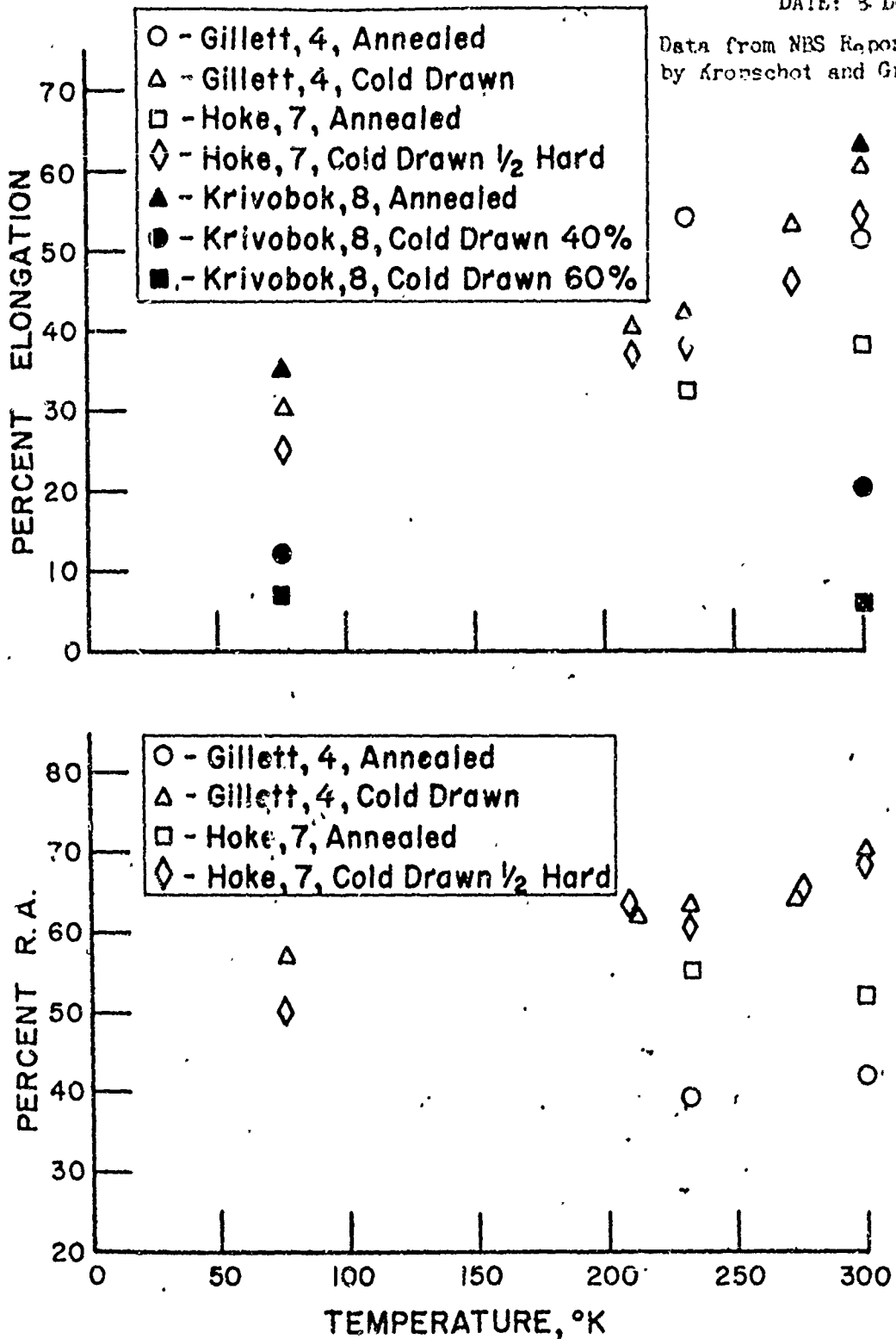


Figure 3. Elongation and reduction of area of 301 stainless steel.

Data from NBS report No. 5009,  
 by Kropschot and Graham

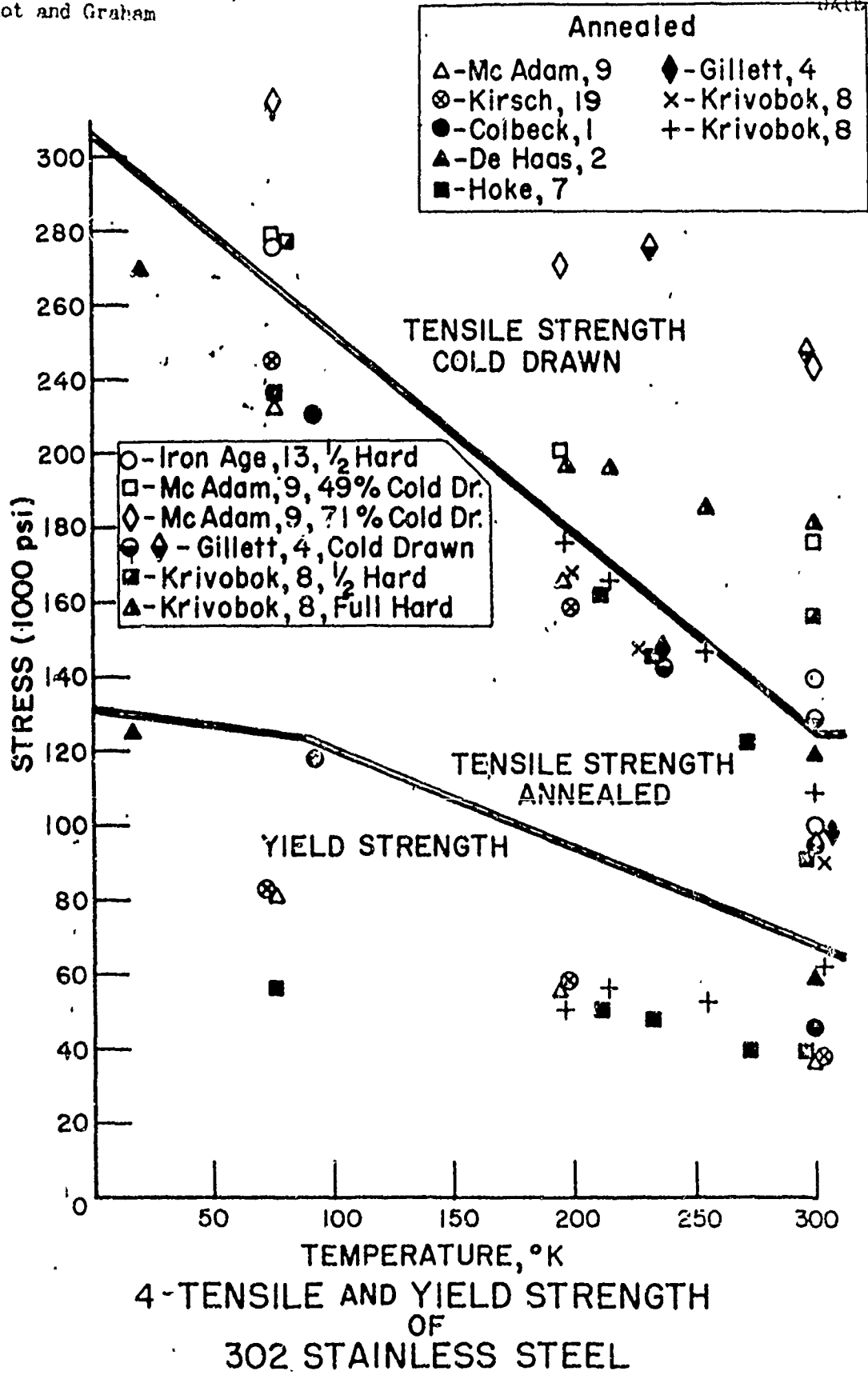


Figure 4. Tensile and yield strength of 302 stainless steel.

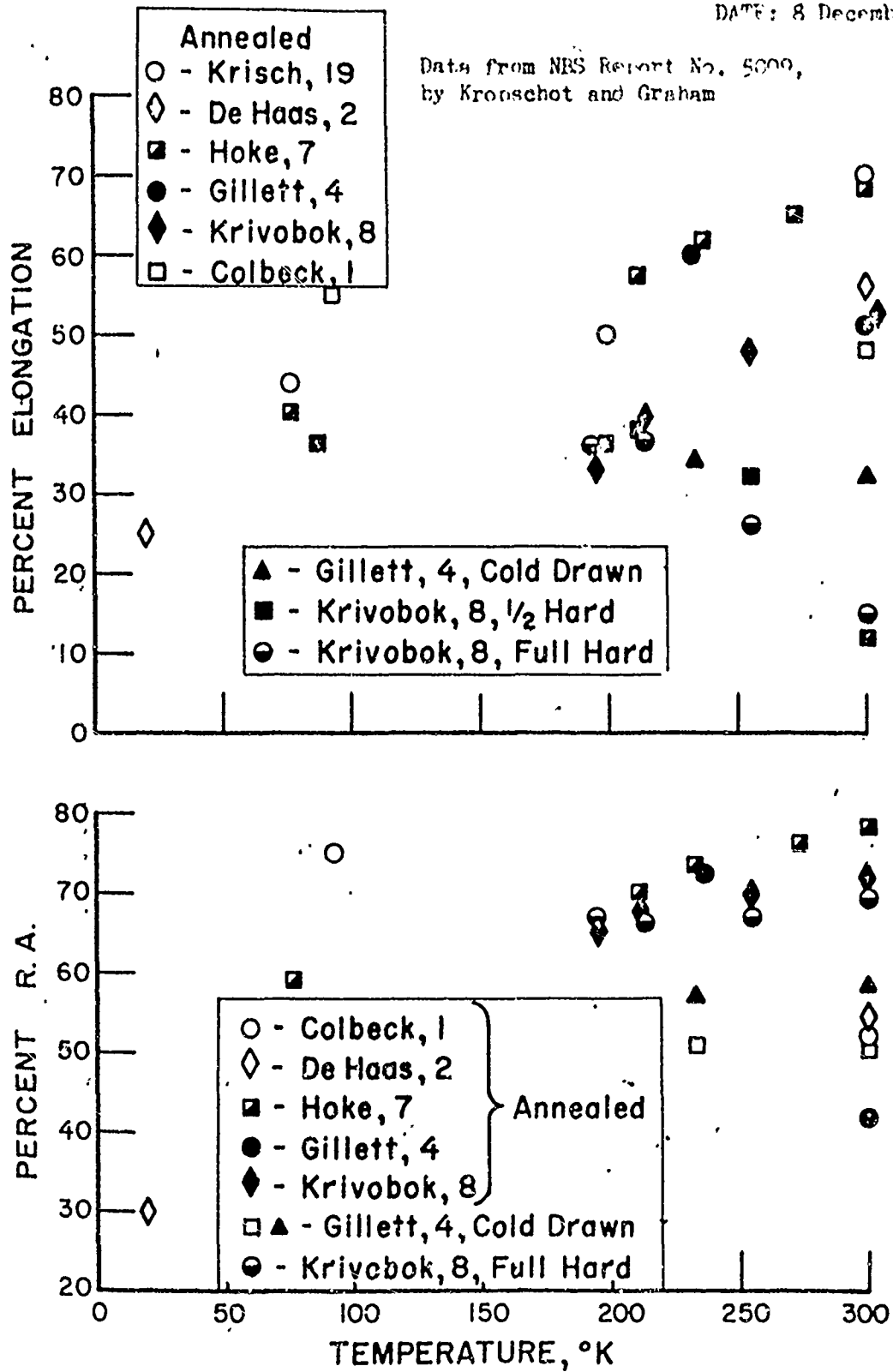


Figure 5. Elongation and reduction of area of 302 stainless steel.

Data from NBS Report No. 5000,  
by Kroppsch and Graham

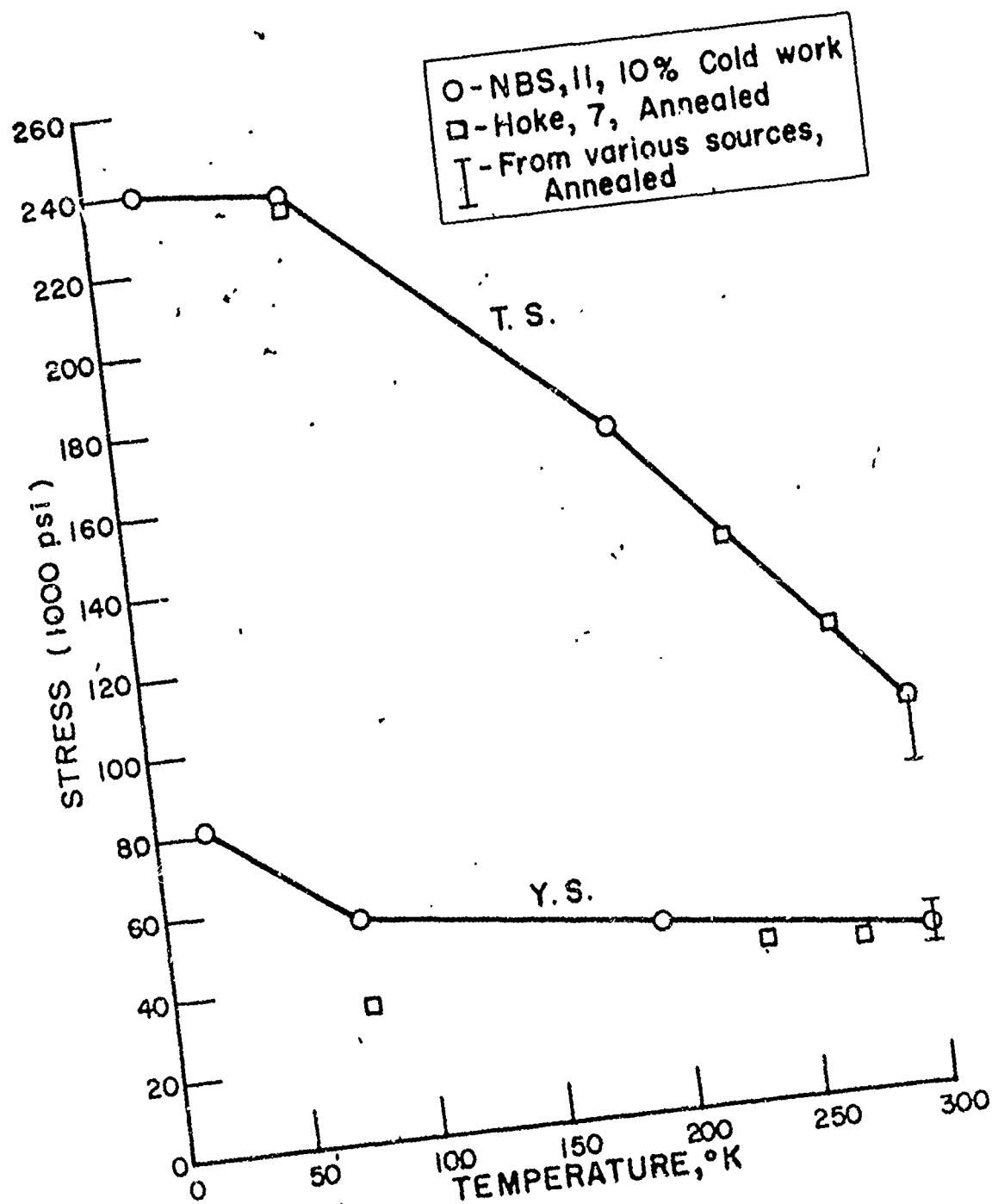


Figure 6. Tensile and yield strength of 303 stainless steel.

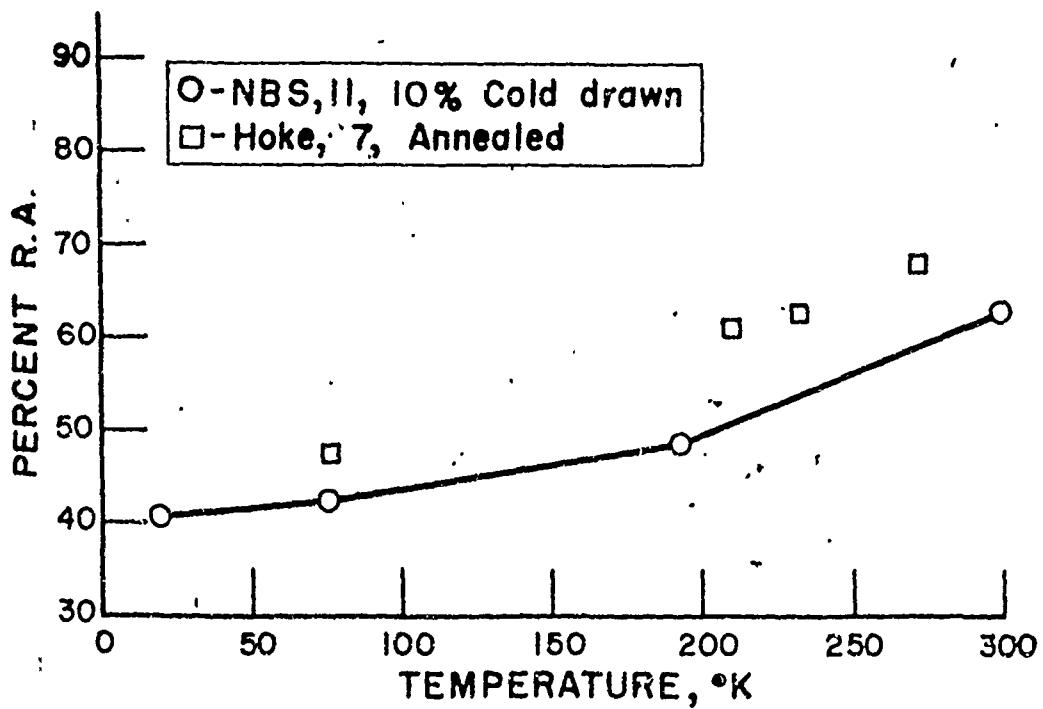
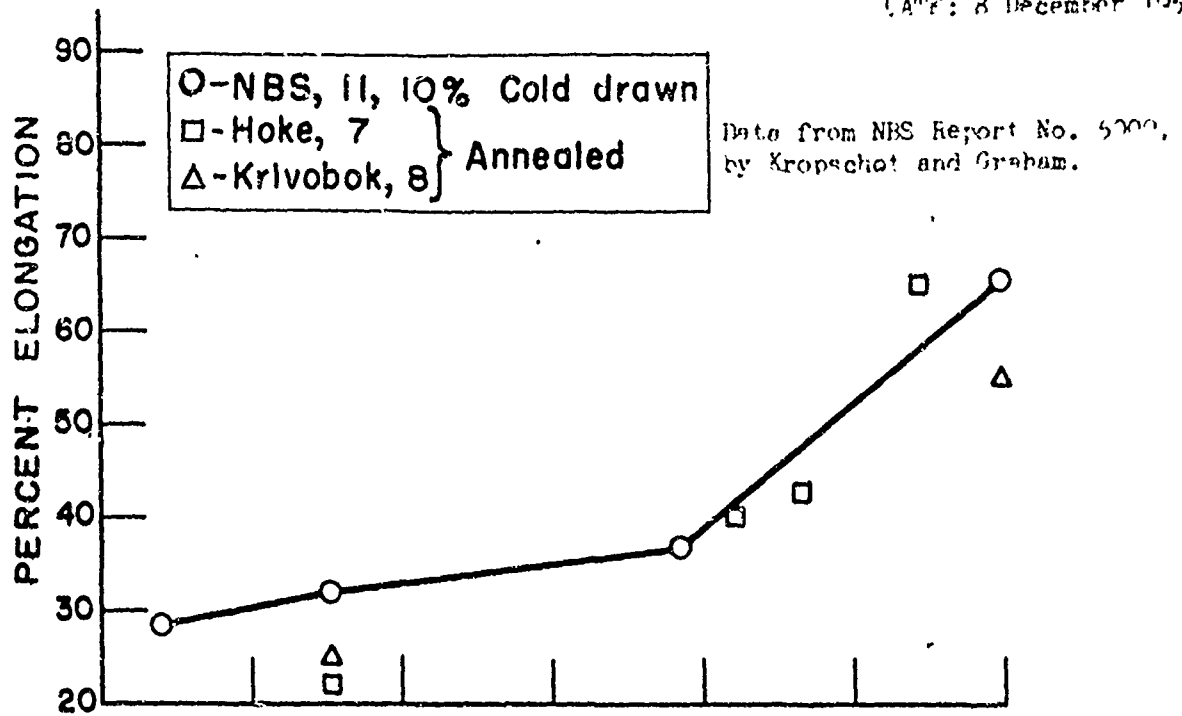


Figure 7. Elongation and reduction of area of 303 stainless steel.

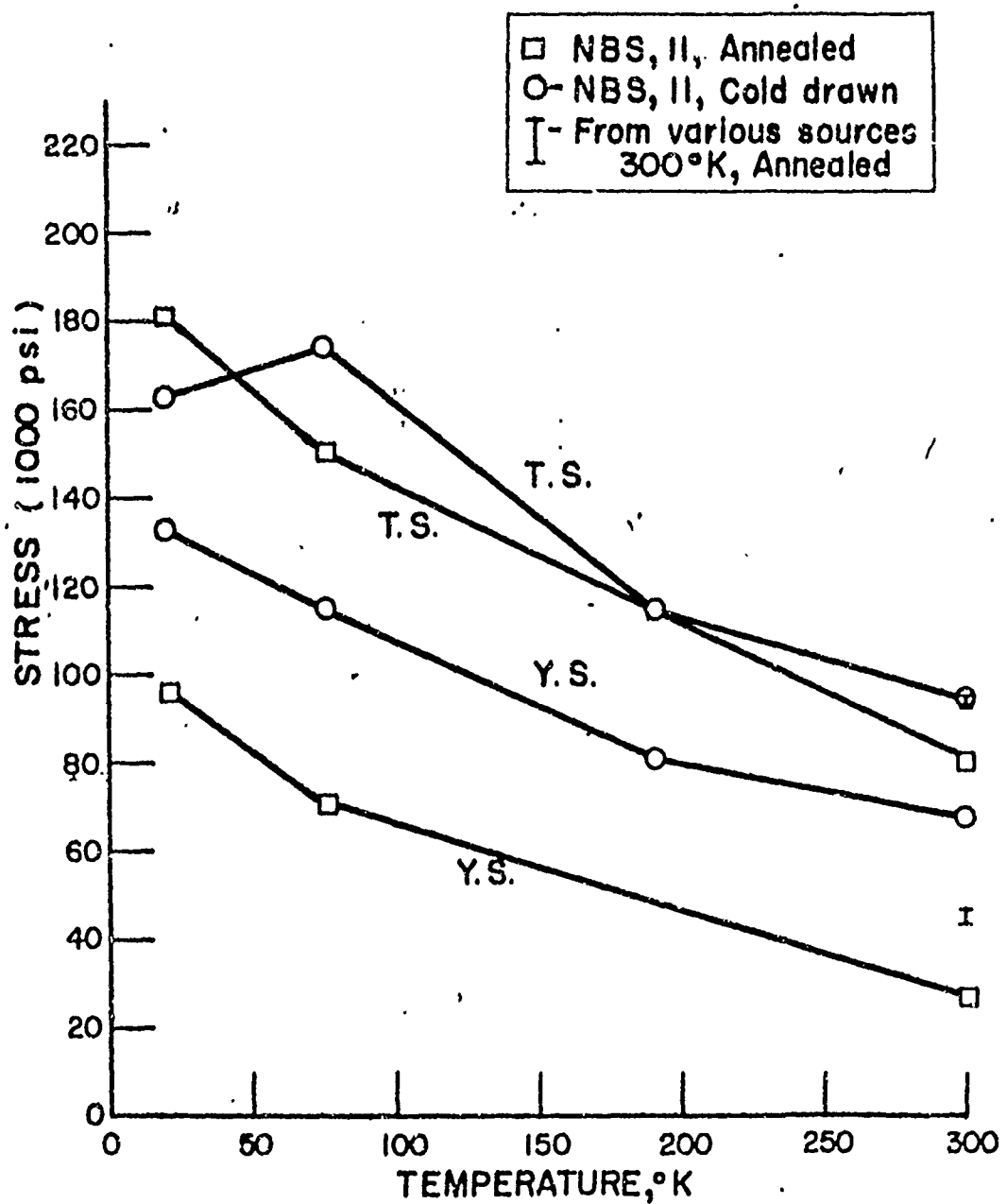


Figure 8. Tensile and yield strength of 310 stainless steel.

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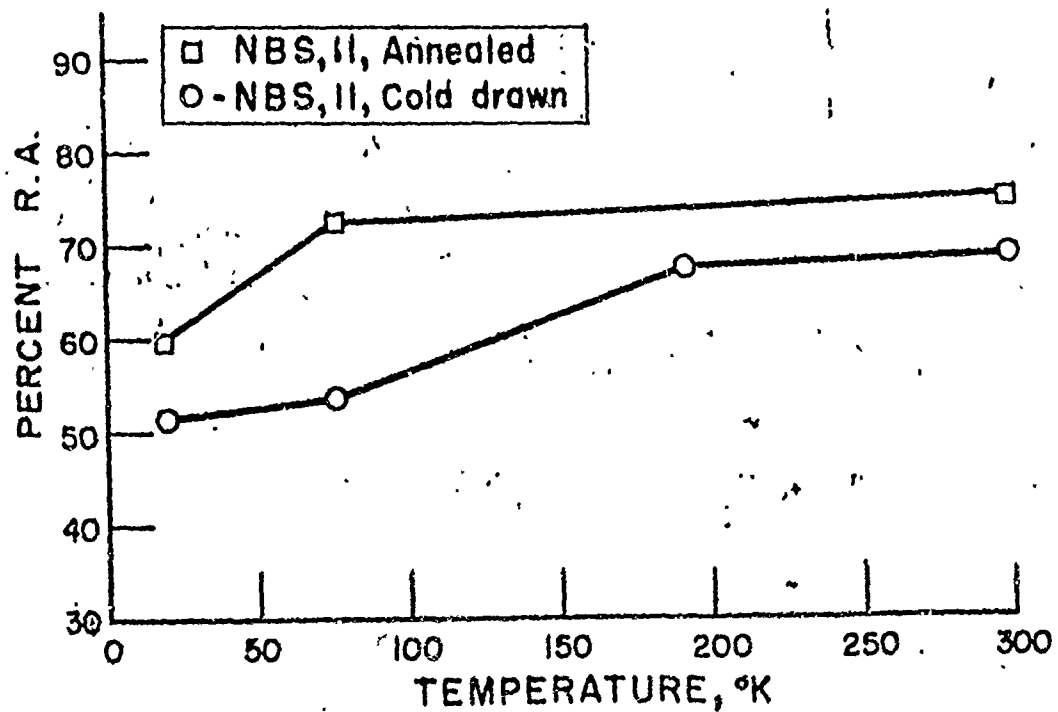
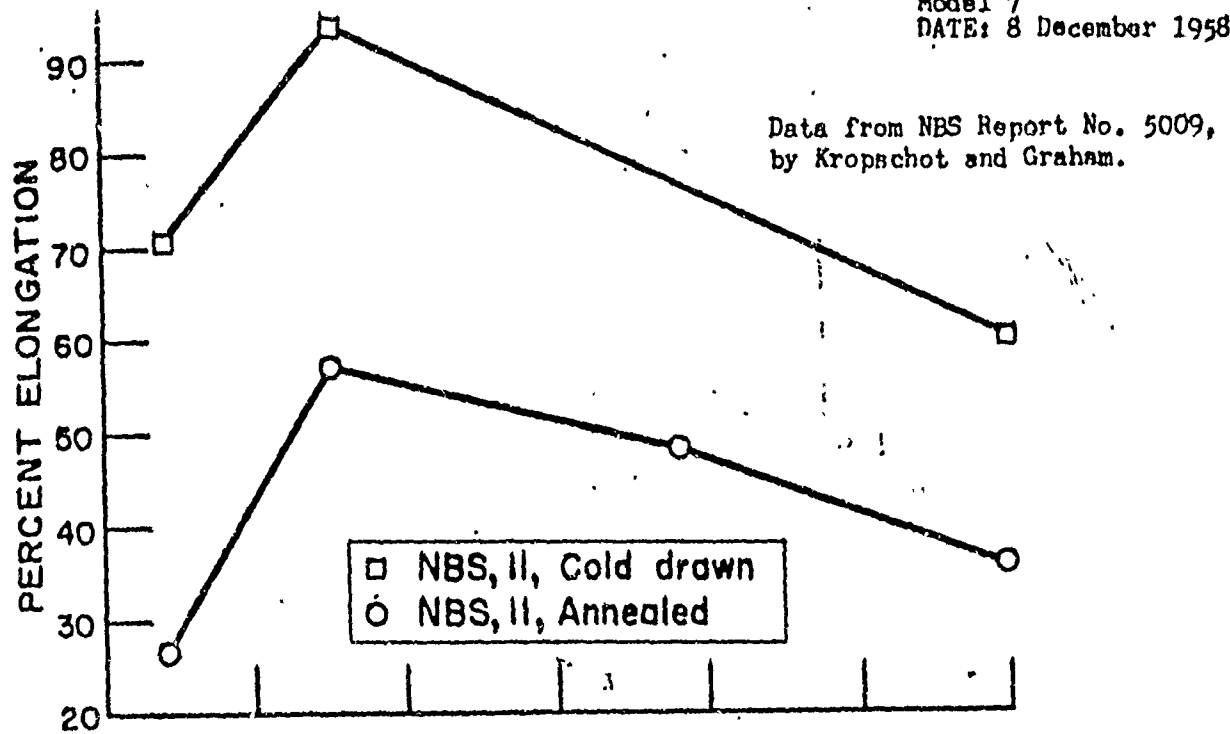


Figure 9. Elongation and reduction of area of 310 stainless steel.

Data from NBS Report No. 5009,  
 by Kropschot and Graham.

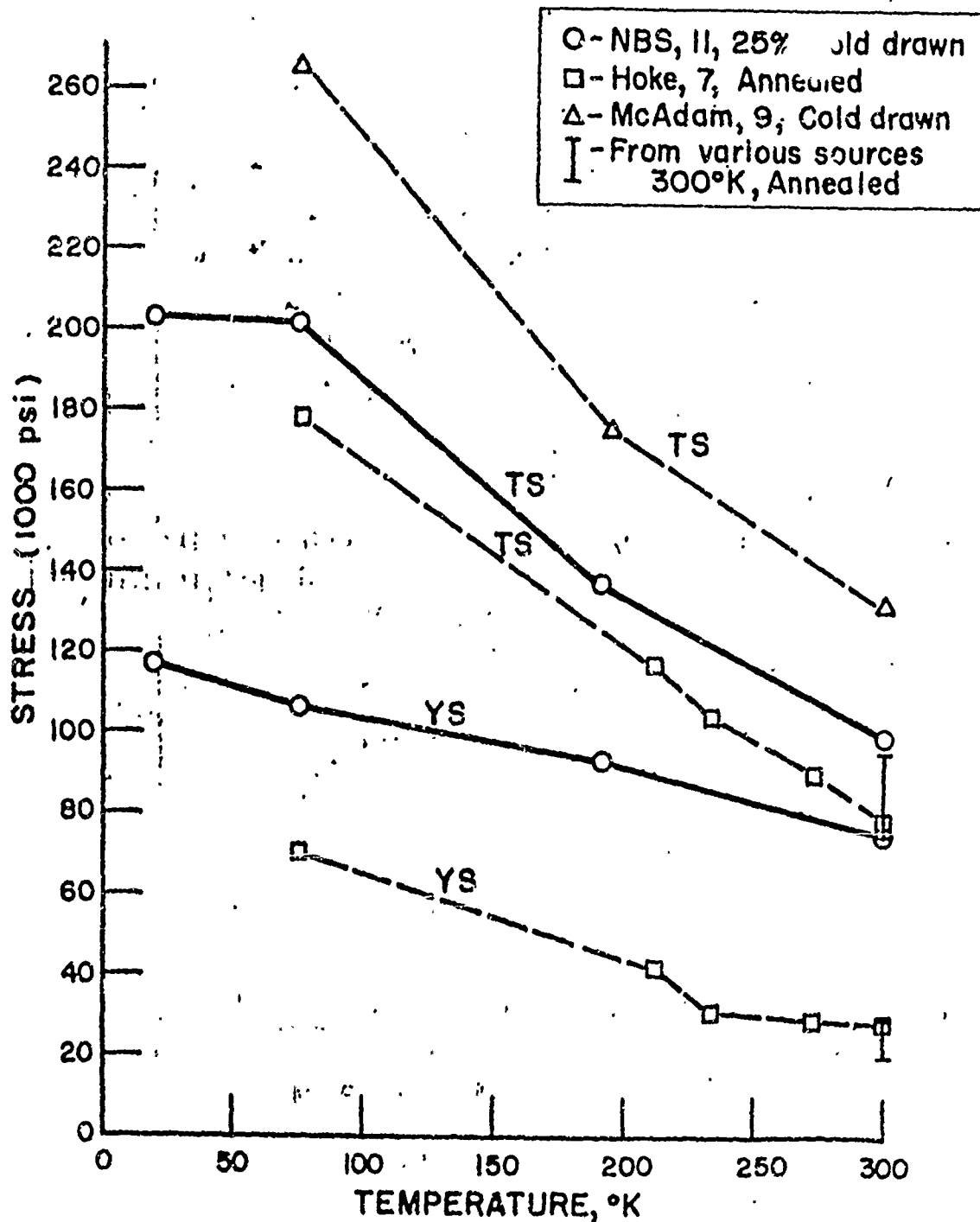


Figure 10 Tensile and yield strength of 316 stainless steel.

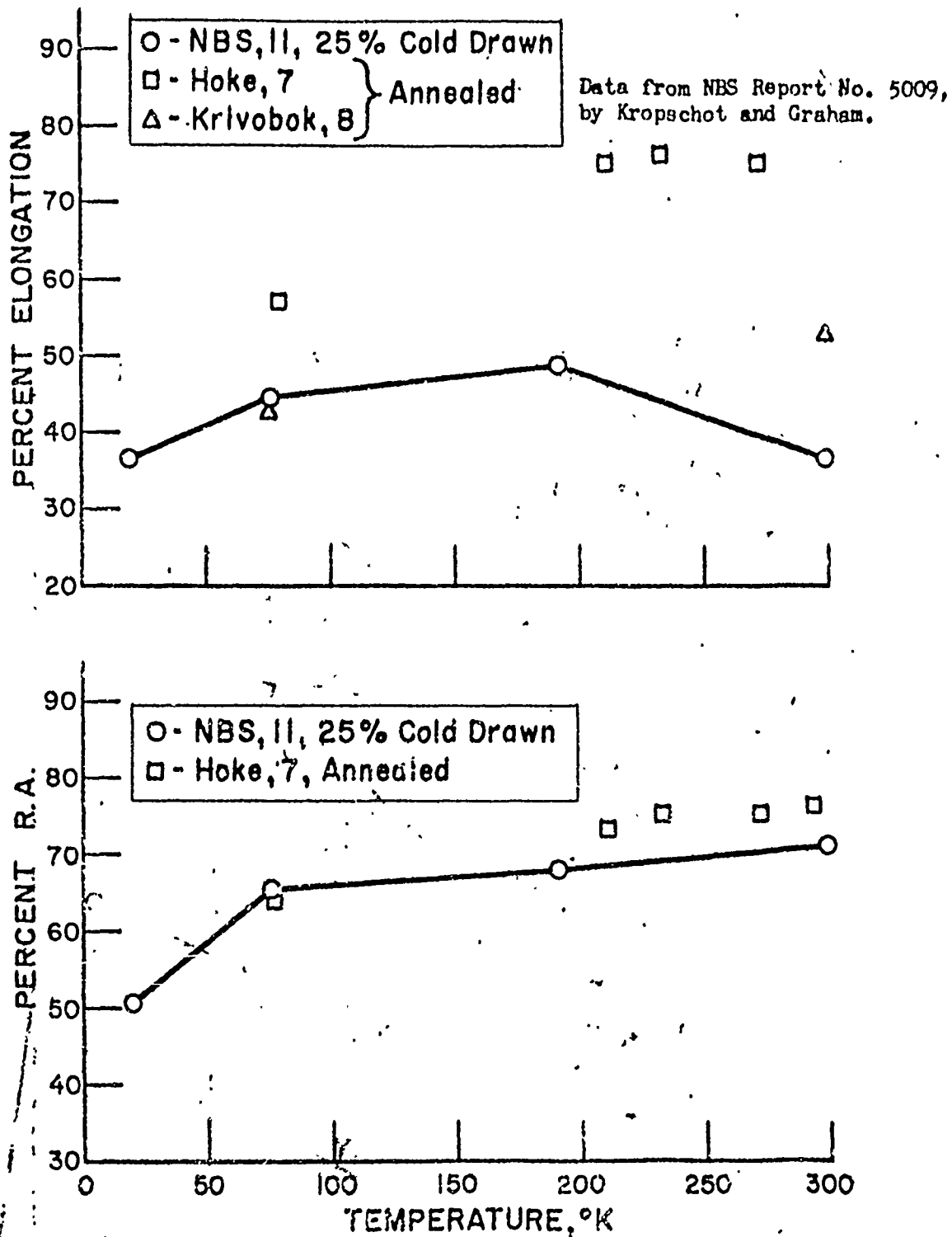


Figure 11. Elongation and reduction of area of 316 stainless steel.

Data from NBS Report No. 5009,  
 by Kropschot and Graham.

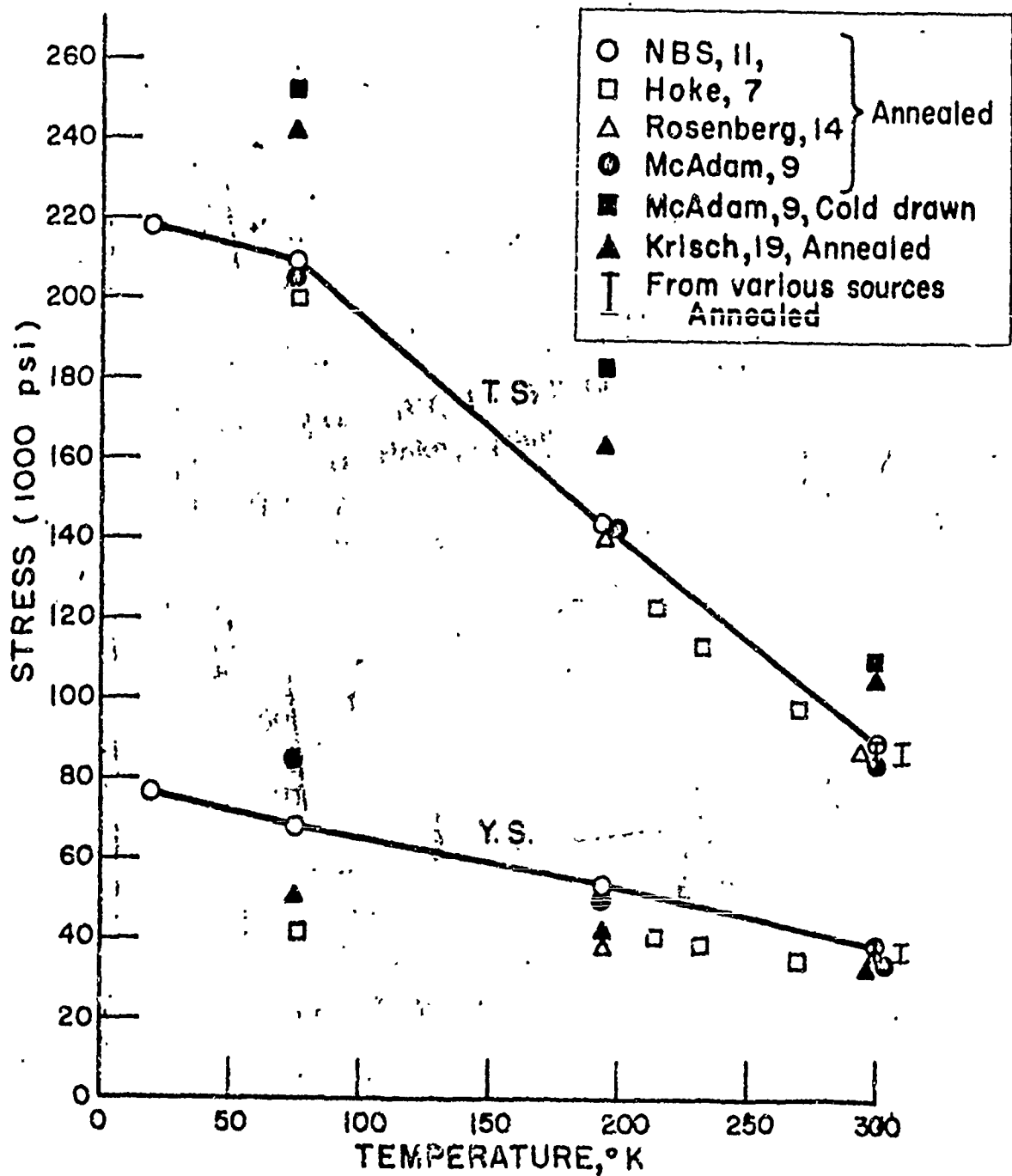


Figure 12. Tensile and yield strength of 321 stainless steel.

Data from NBS Report No. 5009,  
by Kropschot and Graham.

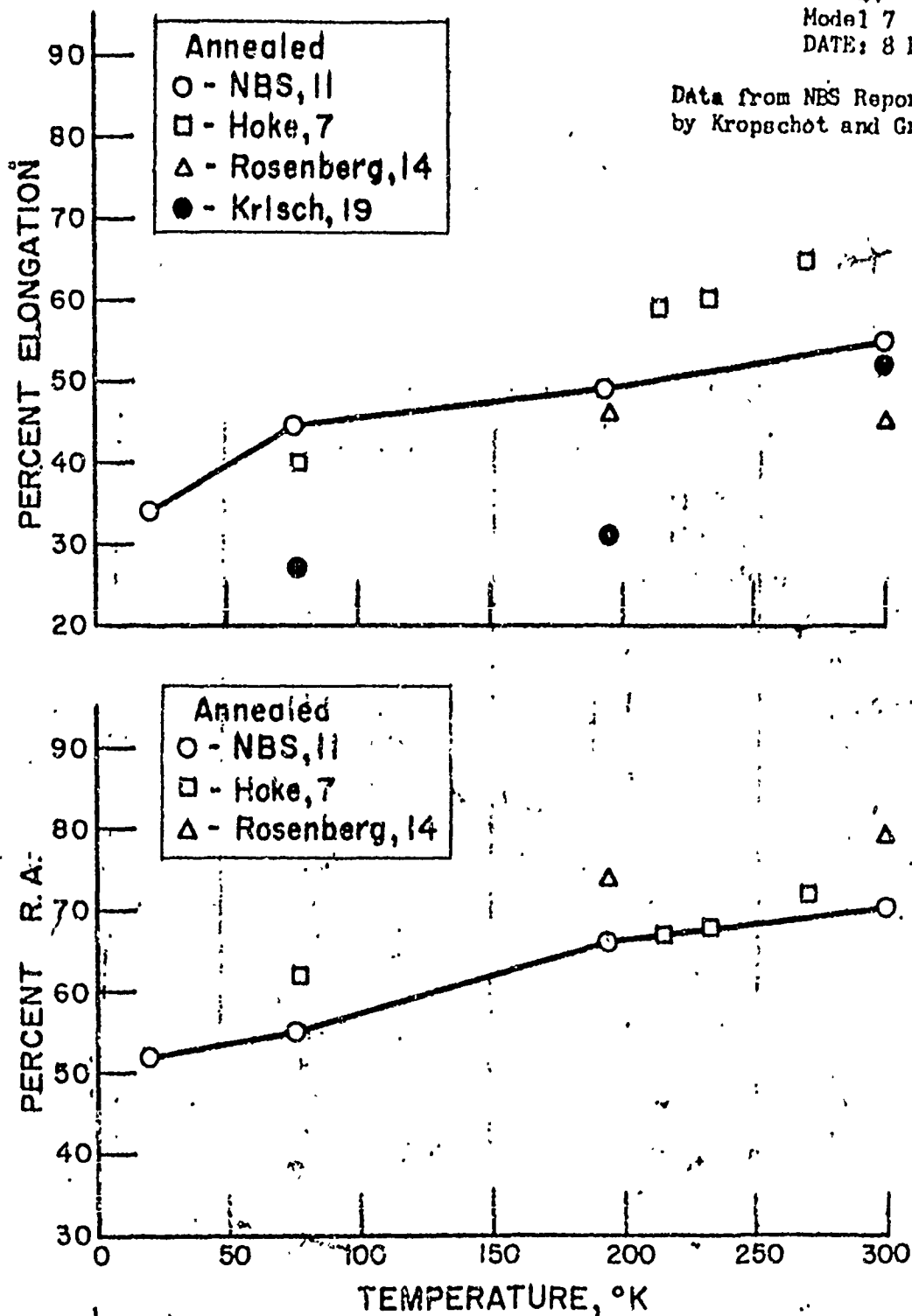


Figure 13. Elongation and reduction of area of 321 stainless steel.

Data from NBS Report No. 5009  
 by Kropschot and Graham

Table I - V-notch charpy impact, ft.-lbs.

Steel	290° to 300°K	190° to 200°K	75° to 90°K
Annealed			
302	110 - 120	---	100 - 120
303	---	---	---
304	110 - 160	110 - 125	90 - 110
310	---	---	---
316	71	81	---
321	110 - 125	120 - 170	110
347	85 - 110	70 - 125	85 - 105
1/4H			
302	108	---	93
304	107	---	85
321	106	---	74
347	70	---	63
1/2H			
302	85	---	64
304	83	---	62
321	79	---	44
347	32	---	37

DATA FROM NBS REPORT NO. 5009,  
BY KROPSCHOT AND GRAHAM

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TABIE II Keyhole charpy impact, ft. lbs.

Steel	290° to 300°K	190° to 200°K	75° to 90°K	20°K
Annealed				
302	80 - 95	---	88	
303	---	---	---	
304	80 - 140	95 - 100	70 - 80	
308	---	---	---	
310	65	---	49	
316	68	62	60 - 70	
321	105 - 110	---	89	
347	60 - 75	60 - 75	60 - 70	
304 CW	25	35	30	26

(Data from 4, 6, 8, 17, 21, 22, 23)

Izod impact, ft. lbs.

Steel	290° to 300°K	190° to 200°K	75° to 90°K
Annealed			
302	---	---	---
303	87	90 - 115	85 - 125
304	90 - 120	115 - 135	120
308	---	---	---
310	---	---	---
316	103	114	110
321	107	120	---
347	109	120	---

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EMG-44

Model 7

DATE: 8 December 1958

DATA FROM NBS REPORT NO. 5009, BY

KROPSCHOT AND GRAHAM

TABLE III - Effect of temperature on Young's modulus  
of cold worked austenitic stainless steels

Steel	Tensile Strength, psi, at 300°K	Modulus ( $10^6$ psi.)	
		300°K	76°K
301	189,000	25.4	28.6
301	231,000	25.8	27.8
302	162,000	26.2	27.2
304	192,000	24.4	26.2
347	155,000	25.0	27.0
347	169,000	23.3	27.6

Data from NBS Report No. 5009,  
by Kropschot and Graham.

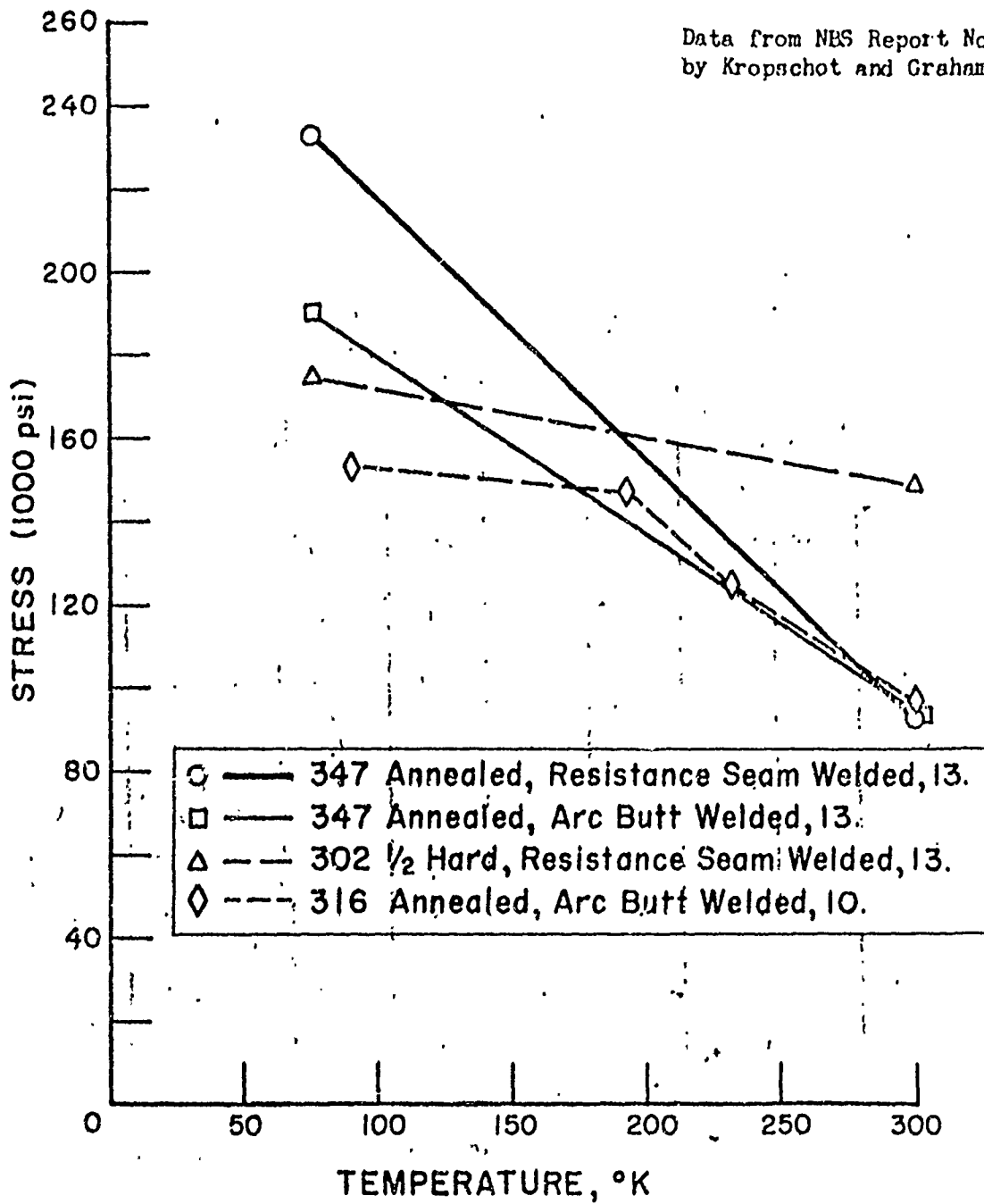


Figure 14. Tensile strength of stainless steel weld joints.

DATA FROM NBS REPORT NO. 5009, BY

KROPSCHOT AND GRAHAM

TABIE IV - Impact strength of stainless steel  
 weld joints in ft. lbs.

Type	Condition	Notch in Weld		Notch in Heat Affected Zone		Notch in Unaffected Zone		Charpy Specimen
		300°K	76°K	300°K	76°K	300°K	76°K	
304	As welded	33	21					Keyhole
304	As welded	59	20					V-notch
304	Annealed	61	31					V-notch
304	As welded	16*	16*	50*	53*			Keyhole
304L	As welded			70	65		71	Keyhole
309	As welded	33	18					Keyhole
310	As welded	34	21					Keyhole
310	As welded	25	28					Keyhole
316	As welded	26	26					Keyhole
316	As welded	43	22					Keyhole
316L	As welded			45	37	54	51	Keyhole
347	As welded	28	16					Keyhole
347	Annealed	30	21					Keyhole

\*Subsize Specimens - 0.200" thick

TABLE V. IMPACT DATA ON WELD METAL. Page 26

Test No.	Type of plate	Type of electrode	Heat treatment*	Per cent ferrite†	Room temperature			-105°F.		EMG-44 Model 7 -320°F.	
					35	35	30	20	22	4.5	5.5
1	301	301	as welded		37.5	38.5					
			annealed		42	41		31	30	24	24
2	302	302	as welded		33	32	34	25.5	20.5	9	10
			annealed		32.5			28			
3	304	304	as welded		40	37		34.5	30.5	24.5	27.5
			annealed		36	34	32	27.5	24	22.5	18
4	304	308	as welded		33	30.5					
			annealed		49	41	42.5	41.5	30	32	32.5
5	310	310	as welded		31	32	32	21	25	19.5	18
			annealed		32.5			22.5		13.5	
6a	316	316	as welded	0.5%	35.5	37.5		30	29.5	30.5	30
			annealed		30.5	35.5		31.5	31.5	23.5	24
6b	316	316	as welded	0.5%	38	35					
			annealed		34	29.5		28.5	27.5	20	18
7	316	316	as welded	8.0%	34.5	27.5		27.5	25	19	14
			annealed		30.5	27				21	
8a	316	316	stress relieved		34	31.5	30	26.5	24.5	14	13
			stabilized		26	29	30	20.5	21.5	14.5	11
8b	316	316	annealed		31.5	36		29.5	25	22	22
			as welded	8.0%	32	31		29	27.5	17.5	19.5
9	317	317	as welded	5.5%	27	25		17.5	16.5	7.5	7
			annealed		11.5	10.5		7.5	7	3	2.5
10	317	317	as welded	5.5%	31.5	40.5	36.5	28	37	23.5	27.5
			annealed		40						
11	317	317	as welded	2.0%	22.5	20.5		16	17	8.5	10
			annealed		21	20.5		17	15.5	10.5	15.5
12	317	317	as welded	5.5%	12	11	10	7	8	4	4
			annealed			9.5	14.5				
13	318	318	as welded	none	11.5	10		6.5	5	3	2.5
			annealed		27.5	27.5		22.5	22.5	9	17
14	318	318	as welded	0.5%	30	22.5		25.5	22.5	17.5	8.5
			annealed		22	21		15	16	13	12.5
15	318	318	as welded	0.5%	33	30	20.5	29.5	27.5	21.5	19
			annealed		20.5	23	15	15	18	11.5	10.5
16	318	318	as welded	0.5%	22	20					
			annealed		21.5	19	17	14	15.5	7	9
17	318	318	as welded	0.5%	9.5	8		8.5	6.5	5.5	5
			annealed		26	25		18.5	22.5	16	10
18	321	347	as welded	§	32	32		27	24	25.5	18
			annealed		32	28		32	30	23	26.5
19	347	347	as welded	none				28.5			
			annealed		25.5	29		22.5	18.5	20	20
20	347	347	as welded	2.5%	22	27		20	20	13	14
			annealed		27	25		17	14	15.5	13.5
21	347	347	as welded	2.5%	22	22		25.5	25	17	16
			annealed		26	24		25.5	25	20	20
22	347	347	as welded	2.5%	27	33		28.5	26.5	22	18
			annealed		17			17		17	19
23	347	347	as welded	2.5%	26.5	24		15.5	14.5	13	9.5
			annealed		22	19		18	15	7	20
24	347	347	as welded	2.5%	27	24.5		27.5	24.5	20	23.5
			annealed		20.5			20.5		20	22.5
25	347	347(a)	as welded		28	25		22.5	23	17.5	13
			annealed		31	28		27	20	22.5	21

\* Heat treatments were as follows:

as welded

stress relieved 1200° F. 2 hrs.

stabilized 1550° F. 2 hrs.

annealed 1050° F. 1/2 hr. water quenched.

† Ferrite was determined by use of a Aminco-Brenner Magne-Cage, as outlined in "Detection of Ferrite by its Magnetism," by T. V. Simpkinson & M. J. Lagne, "Metal Progress," Feb. 1949, page 164.

§ Not measured but probably the same as test No. 14 since the same electrode was used.

(a) Titania type coating. All other electrodes had lime type coating.

Data from International Nickel Co.

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 EMG-44  
 Model 7  
 DATE: 8 December 1958

TABLE VI  
WELDING OF 9 PER CENT NICKEL STEEL WITH INCO-800 "A"

DATA FROM INTERNATIONAL NICKEL COMPANY

The tensile and yield strength values were of the same order of magnitude as those obtained previously with other Inco electrodes. As most of the elongation occurred in the weld, which comprises only a small portion of the 2-inch gage length, the reported elongation values of 13 per cent are artificially low. Actual elongation of the weld metal probably exceeded 35 per cent.

Operating characteristics of this electrode were more nearly akin to those of chromium-nickel stainless steel than any high nickel alloy electrode yet tried.

The following test values were obtained:

TENSILE TEST - ROOM TEMPERATURE

<u>Heat Treatment</u>	<u>Yield Strength 0.2% Offset, psi</u>	<u>Tensile Strength psi</u>	<u>Elongation % in 2 in.</u>	<u>Red. of Area, %</u>
A.W.	62,000	97,750	13.0	47
S.R.	62,500	99,000	13.5	44

IMPACT TESTS - KEYHOLE NOTCH

<u>Temperature of Test</u>	<u>Impact, Ft.Lb.</u>			
	<u>Weld</u>		<u>Fusion Zone</u>	
	<u>A. W.</u>	<u>S. R.</u>	<u>A. W.</u>	<u>S. R.</u>
70 F	38-1/2	38	35	30
-320 F	32	38	31	27-1/2
	35-1/2	37-1/2	36-1/2	36

HARDNESS DATA

Vickers Hardness 10 DG D.P.

	<u>Plate Average</u>	<u>Heat Affected Zone max.</u>	<u>Weld Average</u>
As Welded	293	363	208
Stress Relieved	267	294	198

LOW TEMPERATURE PROPERTIES OF METALS

Designation	Material	Composition, %					Treatment	Temperature of Test, °F.	Tensile Strength, lb / sq. in.	Yield Point, lb / sq. in.	Elongation in 2" %	Reduction of Area, %	Brinell Hardness
		C	Mn	Ni	Cr	Cu							
A	Swedish Chilled Iron	0.01	0.04	.....	.....	.....	As Forged	Room -296° -423°	52,500 116,500 117,000	41,700 ..... 117,000	23.0 Nil Nil	81.0 ..... Nil	104 230 232
B	0.14% Carbon Steel	0.14	0.07	.....	.....	.....	Annealed 1472°F.	Room -296° -423°	45,700 137,000 155,000	42,700 ..... 155,000	27.5 7.5 0.3	77.5 ..... 2.5	114 281 326
C	0.17% Carbon Steel	0.37	0.20	.....	.....	.....	Annealed 1472°F.	Room -296° -423°	76,200 148,000 151,000	..... ..... 151,000	20.0 17.0 Nil	61.0 39.0 Nil	157 294 316
D	0.78% Carbon Steel	0.78	0.10	.....	.....	.....	Annealed 1472°F.	Room -296° -423°	99,000 151,700 121,000	95,000 ..... 123,000	12.0 Nil 0.2	35.0 ..... Nil	194 325 244
E	2% Nickel Steel	0.14	0.72	1.92	.....	.....	Annealed 1472°F.	Room -296° -423°	76,200 132,000 120,000	..... ..... 120,000	20.0 12.0 Nil	..... ..... Nil	170 269 248
F	25% Nickel Steel	0.16	1.0	24.51	.....	.....	Annealed 1472°F.	Room -296° -423°	170,000 264,000 275,000	170,000 ..... .....	15.0 10.0 8.0	53.0 ..... 36.0	320 524 527
G	31% Nickel Steel	0.70	0.87	31.4	.....	.....	Annealed 1472°F.	Room -296° -423°	76,600 219,000 265,000	67,200 ..... 216,000	29.0 10.0 11.0	45.5 ..... 16.5	162 487 513
H	16% Nickel Steel (Invar)	0.16	0.86	35.8	.....	.....	1022°F. Water Quench	Room -423°	81,000 141,000	52,500 127,000	32.0 20.5	57.5 59.5	150 302
I	57% Nickel Steel	0.34	1.31	57.5	.....	.....	As forged	Room -423°	107,000 161,000	72,400 107,000	31.5 35.5	59.5 54.0	177 346
J	Ni-Cr Steel	0.25	0.40	2.67	0.64	.....	Annealed 1472°F.	Room -296° -423°	79,500 137,000 119,000	62,500 ..... 119,000	21.0 17.0 Nil	59.0 54.0 Nil	159 281 235
K	Ni-Cr Steel	0.35	0.56	3.34	0.71	.....	1562°F. Oil Quench Draw 1200°F.	Room -423°	146,000 241,000	131,000 243,000	13.5 4.5	59.5 48.5	284 479
L							Draw 572°F.	Room -423°	241,000 378,000	238,000 297,000	6.0 0.9	51.5 Nil	466 605
M	18-8 Stainless	0.12	0.24	8.1	18.8	.....	2100°F. Water Quench	Room -423°	117,000 268,000	58,000 125,000	56.0 25.0	51.5 30.5	176 516
N	Ni-Mn Steel	1.0	6.05	17.9	.....	.....	1922°F. Water Quench	Room -296° -423°	114,000 168,000 175,000	51,000 ..... 150,000	51.0 42.0 13.0	64.0 ..... 25.5	159 355 376
O	Ni-Mn Steel	1.18	6.05	24.3	.....	.....	1922°F. Water Quench	Room -296° -423°	121,000 188,000 195,000	58,000 ..... 161,000	61.0 67.0 26.0	59.5 47.0 50.5	191 286 404
P	Cr-Ni-Fe Alloy	0.46	2.41	14.40	59.3	.....	As Forged	Room -423°	122,000 174,000	112,500 135,000	22.0 28.5	58.0 40.5	230 368
Q	Manganese Steel	1.27	12.69	.....	.....	.....	1832°F. Water Quench	Room -296° -423°	148,000 137,000 146,000	77,300 ..... 146,000	44.5 2.5 Nil	39.0 ..... Nil	227 364 305
R	Monel	.....	.....	67.0	.....	30.2	As Forged	Room -423°	86,500 142,000	48,000 96,300	36.0 38.5	74.5 61.0	145 297

DATA FROM DE HAAS AND HADFIELD..... TABLE VII

TABLE VIIIWROUGHT AUSTENITIC STEELS FOR LOW TEMPERATURE SERVICE

	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cu</u>	<u>X</u>
A. Hadfield Manganese Steel	1.4	12.1	0.1				
B. AMS 5624 Annealed	0.60	4.4	0.5	12.9	3.3		Mo-0.4
C. Mn-Ni-Cr-Cu Austenitic Stain.	0.07	4.9		5.4	18.0	1.3	
C. Mn-Cr-Cu-N Austenitic Stain.	0.10	14.1		0.7	17.6	1.2	N-0.30

C &amp; D Annealed 1950°F, Air Cooled

<u>Temperature (°F)</u> <u>of Specimen Tested</u>		<u>Tensile</u> <u>Strength</u> <u>(psi)</u>	<u>Elongation in 1</u> <u>Inch (%)</u>	<u>Reduction of</u> <u>Area</u>	<u>Charpy</u> <u>a. (Keyhole</u> <u>b. (V-Notch) (Ft-Lbs)</u>
A.	80	158,000	62.5	37.7	
	-165	138,000	25.0	23.3	
	-235	137,000	12.0	11.3	
	-320	137,000	4.0	4.9	
B.	80	104,000	77		114a
	-100	124,000	80		94a
	-320	155,000	29		44a
C.	80	95,000	81.0	80.7	193b
	-100	163,000	59.5	68.9	153b
	-320	234,000	46.5	58.3	68b
D.	80	111,000	70.8	76.8	211
	-100	154,000	72.5	74.8	160
	-320	211,000	20.0	19.2	45

Data from Payson, Crucible Steel Company.  
From Conference on Materials and Design  
for Low Temperature Service, Department of  
the Army, Corps of Engineers.

Betty and Mudge, Properties of Various Alloys at Subzero Temperature, Iron Age, 14 Nov. 1946

SAE 1010

<u>Temperature</u> <u>°F</u>	<u>Yield</u> <u>Strength</u> <u>(psi)</u>	<u>Ultimate</u> <u>Strength</u> <u>(psi)</u>	<u>Elongation % in 2"</u>
68	28,000	41,000	40
-317	117,000	117,000	0

# MECHANICAL PROPERTIES OF AUSTENITIC STEELS AT LOW TEMPERATURES

14.7 CR - 10.0 NI - 0.11 C  
 Water quenched from 2010°F.

Data from Colbeck, MacGillivray,  
 Manning.  
 Trans. Inst. Chem. Engr. 1933, Vol 11.

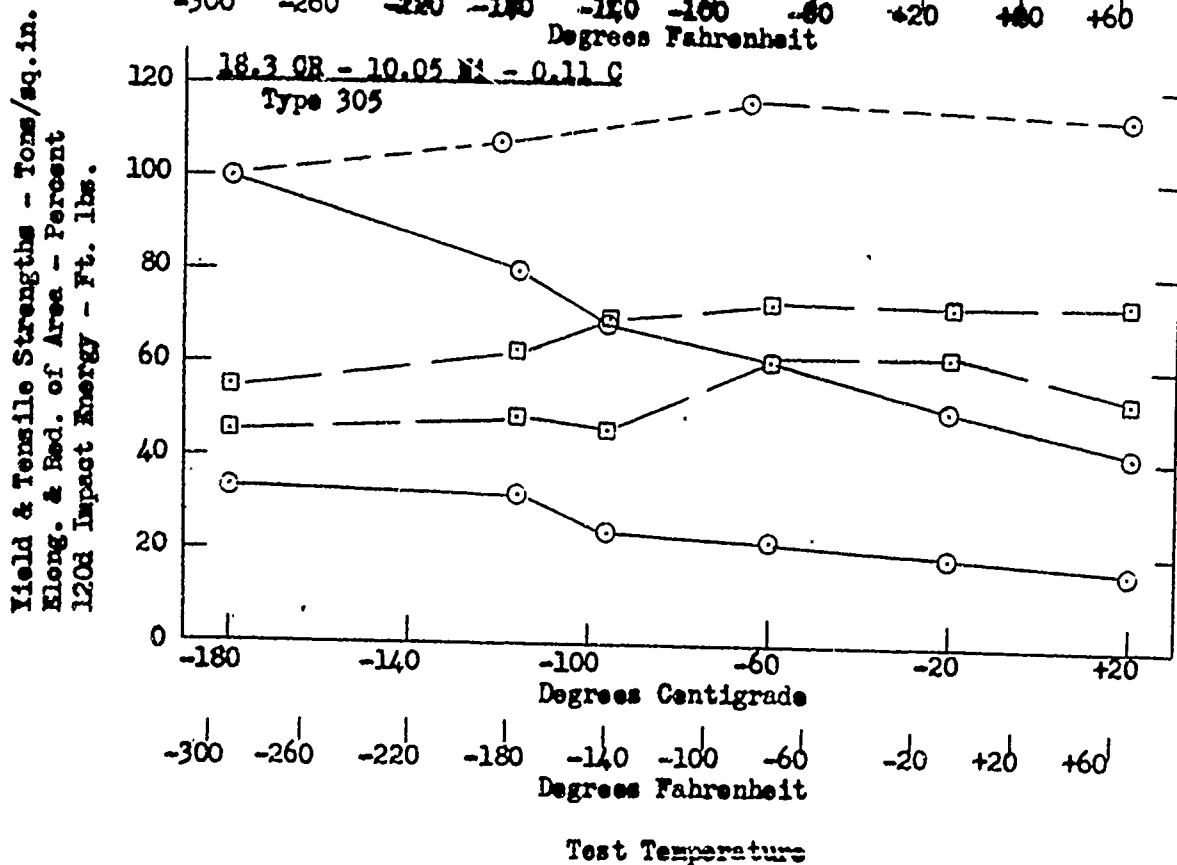
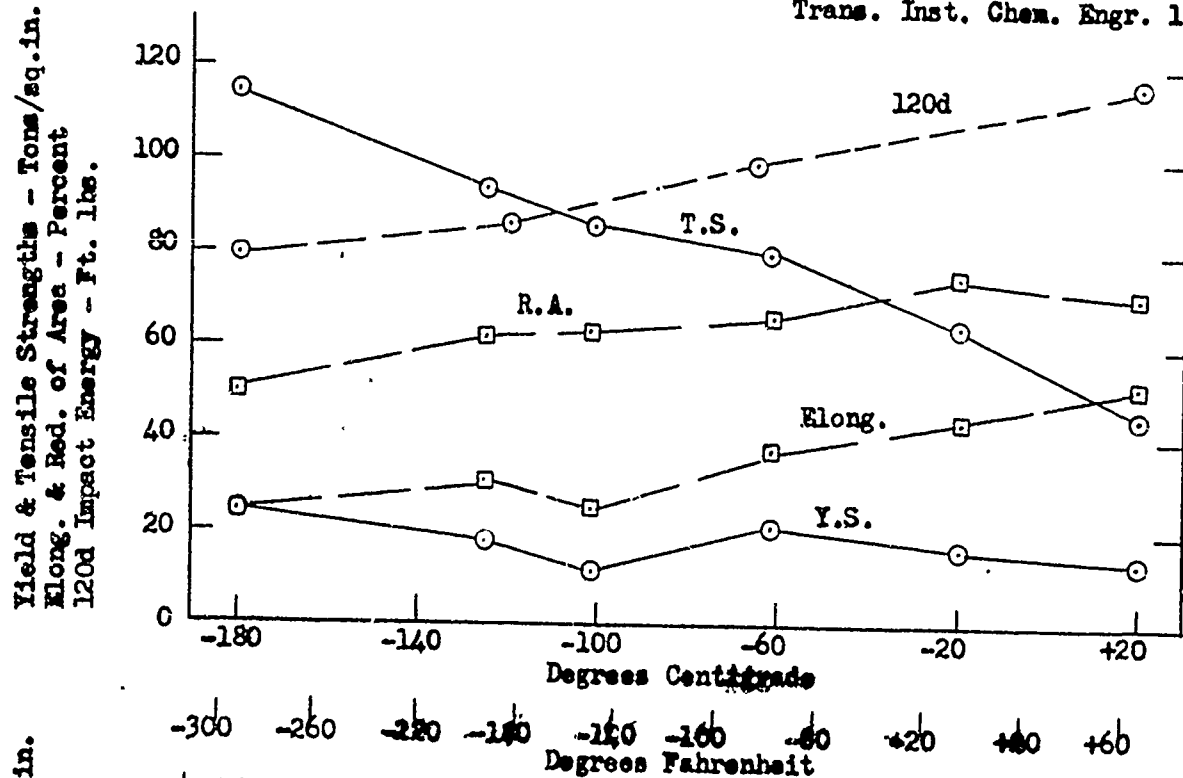


Figure 5.

**TABLE IX**

**TENSILE AND FATIGUE PROPERTIES OF 301 AND 301-M STAINLESS**

**STEEL**

	N <sub>2</sub>	Cr	Ni	Mn	Mo	P	S	C	Si
301	0.039	17.4	7.11	0.97	0.12	0.023	0.013	0.10	0.42
301-M	0.133	17.3	6.78	0.86	0.14	0.021	0.024	0.09	0.44

**BASE METAL PROPERTIES**

	301		301-M	
	<u>+70°F</u>	<u>-320°F</u>	<u>+70°F</u>	<u>-320°F</u>
Yield Str., psi	201,000		192,000	
Ultimate Tensile Str. psi	208,000	350,000	202,000	350,000
Elongation, %	9		14	

**WELDED JOINT PROPERTIES**

Tension Fatigue Tests of .020" Welded Sheet, Cycled From  
0 to 144,000 psi

Number of Cycles to Fracture

301		301-M	
<u>+70°F</u>	<u>-320°F</u>	<u>+70°F</u>	<u>-320°F</u>
925	2878	712	179
991	2461	624	746
888	2674	579	94
		627	169

**TABLE X**

**STATIC TENSION TESTS OF .020" WELDED SHEET**

**TYPE 301**

<u>Weld Configuration</u>	<u>Resistance Spot Weld</u>			<u>Heli-Arc Weld</u>		
	<u>+70°F</u>	<u>-320°F</u>	<u>%CHG.</u>	<u>+70°F</u>	<u>-320°F</u>	<u>%CHG.</u>
Res. Lap spots each side	207,000	247,000	+22.4	183,000	226,500	34.7
Res. lap RP* spots each side	212,000	-	-	193,000	-	-
Heli-lap spots each side	200,000	-	-	184,000	231,000	+25.5
Heli-lap RP* spots each side	204,000	-	-	182,000	233,000	+28.2

**TYPE 301-N**

Res. lap spots each side	198,000	183,000	-7.6	182,000	214,500	+17.9
Res. lap RP* spots each side	198,000	167,900	-15.2	182,000	213,400	+17.3
Heli-lap spots each side	185,000	169,900	-8.2	166,000	-	-
Heli-lap RP* spots each side	180,000	188,200	+4.6	170,000	-	-

\* RP: Roll Planished.

**TABLE XI**

**STATIC TENSION TESTS ON WELDED JOINTS OF 301 AND 301-N; SAME JOINT**  
**AS IN FATIGUE TESTS 0.020" SHEET**

**Tensile Strength**

	<u>301</u> <u>+70°F</u>		<u>301-N</u> <u>+70°F</u>
	208,900		211,800
	205,400		208,500
	<u>210,500</u>		207,900
AVERAGE	208,200		209,200
			209,000
			<u>208,300</u>
		AVERAGE	209,100
	<u>-320°F</u>		<u>-320°F</u>
	250,600		186,900
			191,000
	243,300		220,600
			209,000
	<u>252,700</u>		187,500
			184,000
AVERAGE	248,900		218,900
			202,700
			180,000
			163,000
			181,360
			<u>185,200</u>
		AVERAGE	192,500

**TABLE XII**

**MECHANICAL PROPERTIES OF VARIOUS SHEET MATERIALS AFTER EXPOSURE**

**FOR 8 HOURS AT -320°F(1)**

<u>Material</u>	<u>Treatment</u>	<u>Hardness</u>	<u>Test Temp.</u>	<u>TSx10<sup>3</sup> psi</u>	<u>.2% YSx10<sup>3</sup> psi</u>	<u>% Elong. 2"</u>	<u>Charpy "V" Notch Impact (2) Ft. Lbs.</u>
Full Hard 301	Cold Rolled 40%	43 Rc	RT -320°F	192 291	165 182	19 15	33(3) 33
Full Hard 201	Cold Rolled 40%	43 Rc	RT -320°F	197 256	173 222	10 9	34(3) 33
Extra Hard 301	Cold Rolled 65%	49 Rc	RT -320°F	252	229	3	
AM-350	(SCT) 3 hrs. at -100°F+3 hrs. at 850	45 Rc	RT -320°F	209 293	183 253	16 13	40(3) 6
Extra Hard AM-350	3 hrs. at -100°F + cold rolled + tempered	51 Rc	RT -320°F	252 334	252 332	3 2	24 10
Hardened 419	1950°F, AC+30 min. at 1000°F	52 Rc	RT -320°F	275 242	210 237	12 1	17 3

- (1) Samples were held 7 1/2 hours at -320°F, warmed to room temperature, and then held 1/2 hour at temperature before testing.
- (2) Impact values were obtained from samples made of three pieces .394" x 2.168" x .065" welded together. Values were then corrected to standard thickness of .394".
- (3) Samples were not held at -320°F prior to testing.

TABIE XIII

TENSILE PROPERTIES OF STAINLESS STEELS EXPOSED TO LIQUID HELIUM

Material	BEFORE EXPOSURE				AFTER EXPOSURE			
	0.2% Yield Str. psi	Ten. Str. psi	Elong. 2" %	Rockwell Hardness	0.2% Yield Str. psi	Ten. Str. psi	Elong. 2" %	Rockwell Hardness
Type 304	39,000	87,000	63	B81.5	37,500	87,500	65.5	B81
Type 304 (1/2 Hard)	136,500	151,000	11	C35	139,000	154,000	10	C35
Type 321	26,000	76,500	65	B64	25,000	81,000	58	B75
Type 347	42,000	88,500	53	B83	42,000	89,000	54	B83.5
Type 310	30,500	79,500	54	B73	31,000	80,500	55	B74
Incoloy	34,000	85,000	45	B76.5	34,000	85,000	46	B78
12 Cr, 8Ni, 2Mo	40,500	88,000	31	B82.5	43,000	106,000	53	B93.5
18Cr, 8Ni, 2Mo	49,000	111,000	56.5	B92.5	49,000	111,000	55	B88
18Cr, 14Ni, 2Mo	49,500	101,000	39	B88.5	46,500	101,000	42.5	B85.5
30Cr, 14Ni	62,000	106,500	35.5	B94.5	59,000	106,000	36.5	B90

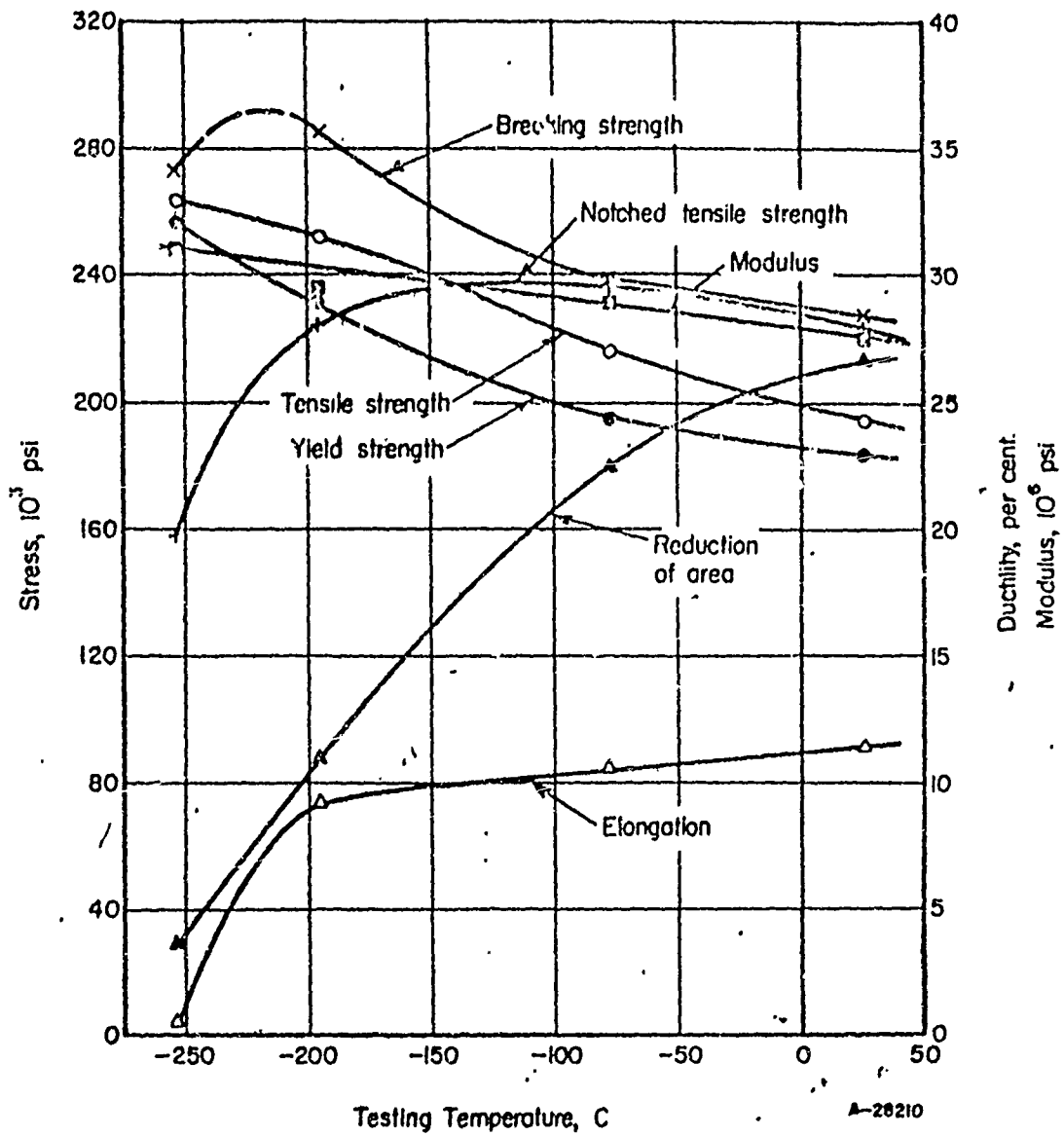


FIGURE 16 MECHANICAL PROPERTIES OF 17-7PH  
 STAINLESS STEEL SHEET IN THE  
 TH-1050 CONDITION

DATA FROM WADC REPORT TR 58-386

Part 37  
 EMI-1/1  
 Model 7  
 DATE: 8 December 1958

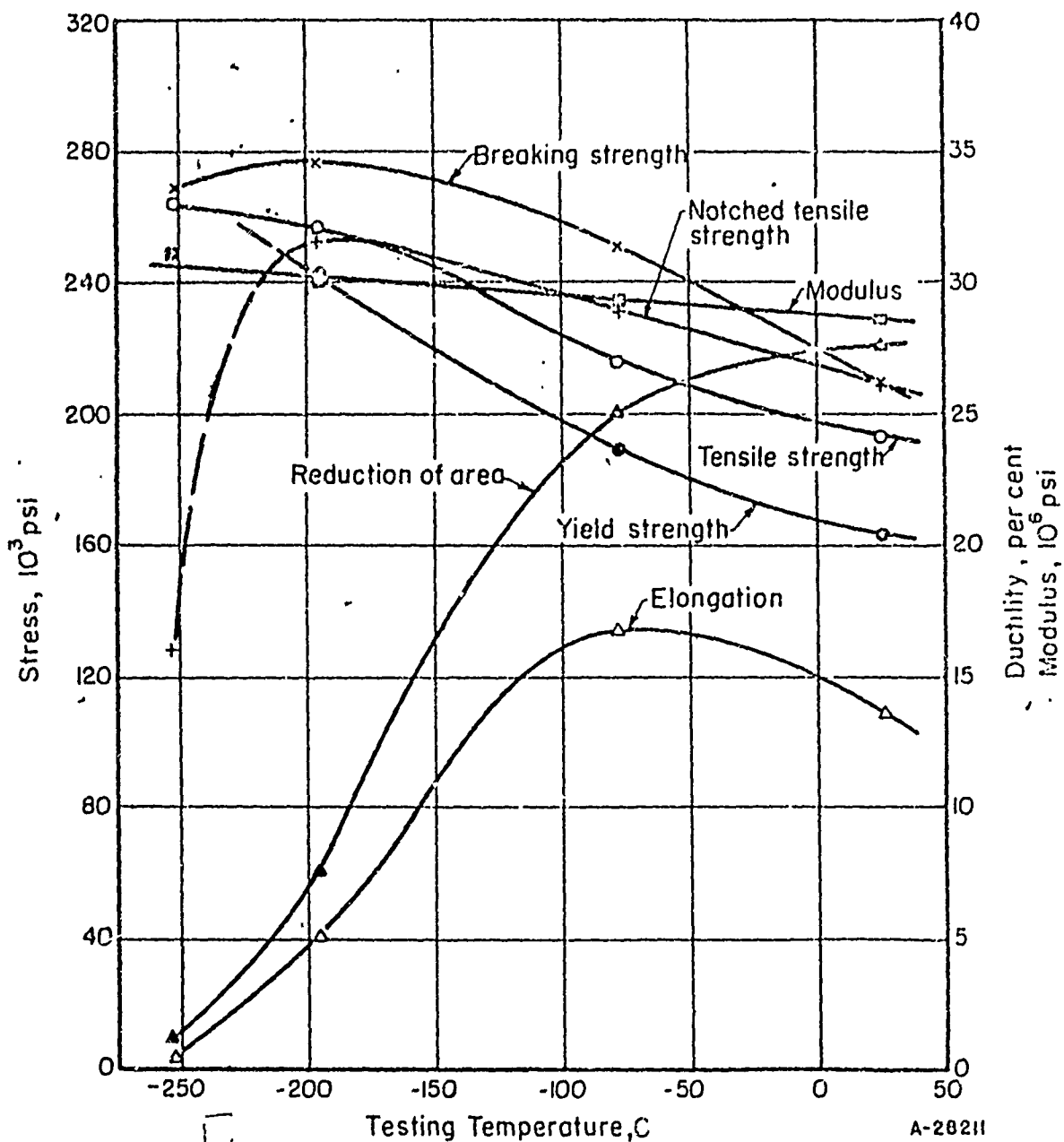


FIGURE 17 MECHANICAL PROPERTIES OF AM-350 STAINLESS STEEL SHEET - SURFACE TREATMENT - DATA FROM WAGC REPORT TR 58-386

**TABLE XIV**

**TENSION PROPERTIES OF AM-350, ALLOAT, 17-7PH TH 1050, C110M**

Source: Bimonthly Progress Report Battelle, Contract Number  
AF 33(616) -3542, Task Number 73605, Jan. 16, 1957

TEST	STRENGTH IN KSI		MODULUS	ELONGATION	
Temp. °F	Time	Yield(2%)	Ultimate	psi x 10 <sup>-6</sup>	Percent in 2"
AM 350					
79°F	Unnotched	162,800	193,000	28.6	13.6
-108	Unnotched	188,500	216,000	29.3	16.7
-330	Unnotched	242,000	257,200	30.0	5.1
79	Notched		208,700		
-108	Notched		231,500		
-330	Notched		254,500		
ALLOAT					
79	Unnotched	135,000	138,800	15.6	16.8
-108	Unnotched	162,800	170,300	16.2	9.9
-330	Unnotched	225,300	230,000	17.1	4.9
+79	Notched		183,500		
-108	Notched		214,000		
-330	Notched		276,000		
C110M					
79	Unnotched	127,000	140,000	15.5	14.8
-108	Unnotched	169,000	176,500	16.6	13.3
-330	Unnotched	247,000	260,000	17.3	5.2
79	Notched		151,000		
108	Notched		191,000		
-330	Notched		254,800		
17-7PH, TH 1050					
79°F	Unnotched	183,500	194,500	27.5	11.4
-108	Unnotched	195,200	252,000	28.9	10.8
-330	Unnotched	230,000	252,000	29.5	9.3
79°F	Notched		234,000		
-108	Notched		237,000		
-330	Notched		224,000		

TABLE XVAM-350 STAINLESS V-NOTCH CHARPY IMPACT TEST - ALLEGHENY  
LUDLUM STEEL CORPORATION

<u>Test</u> <u>Temperature °F</u>	<u>Impact</u> <u>Resistance</u> <u>Ft.Lbs.</u>
--------------------------------------	--

RT	35
-40	28
-100	26
-200	21
-300	15
-320	15

Heat treatment - annealed  
1 hour at 1750°F air cooled -  
3 hours at -100°F, 2 Hours at  
850°F air cool

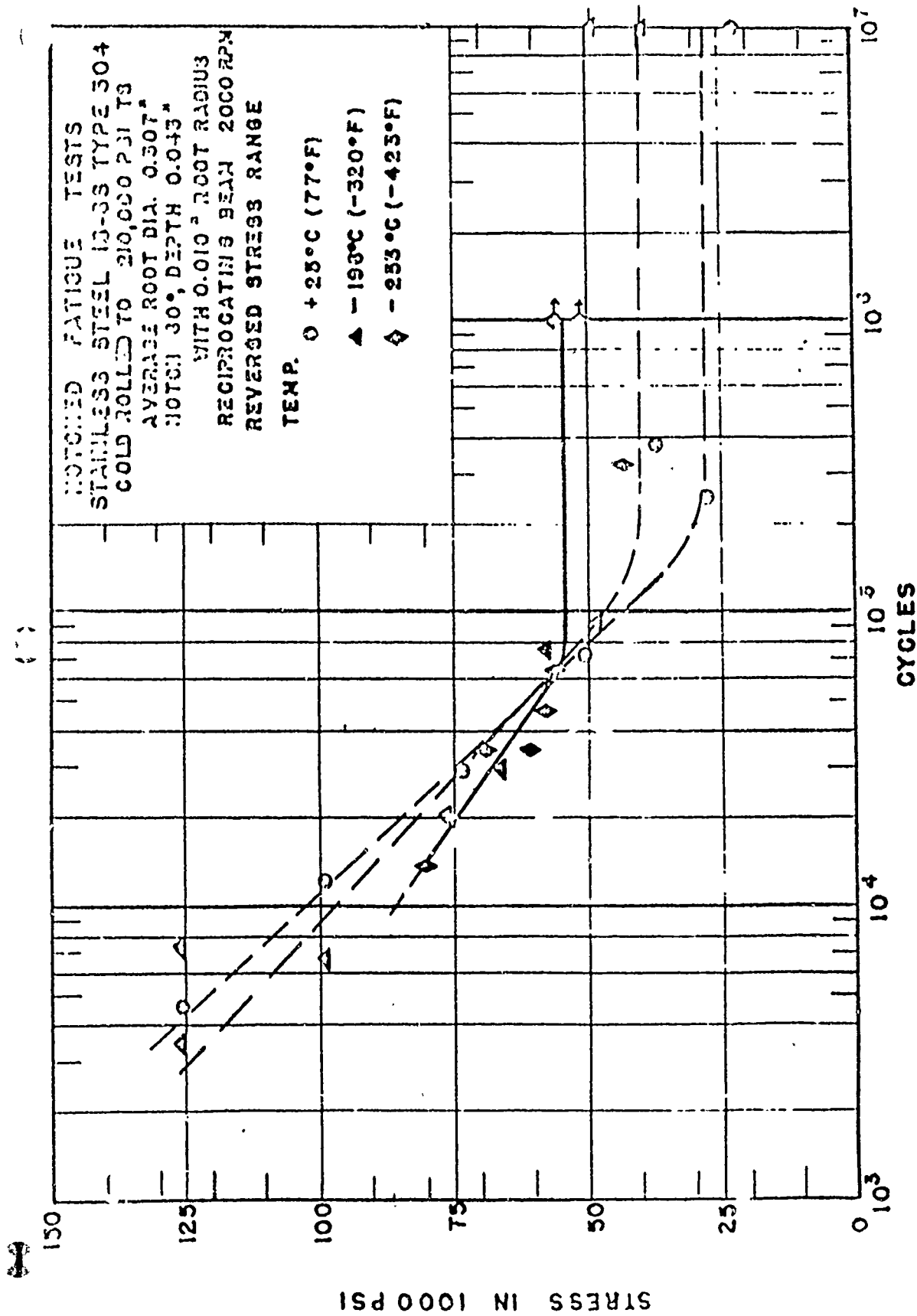


FIGURE 8. RECIPROCATING BEAM FATIGUE STRENGTH OF 18-8S STAINLESS STEEL AT VARIOUS TEMPERATURES. DATA FROM NADCO REPORT 5662.

TABLE XVI

KRIVOBOK AND TALBOT

TABLE IX.--EFFECT OF SHORT-TIME AGING ON PROPERTIES AT ROOM TEMPERATURE.

Material	Conditions of Rolling <sup>a</sup>	Subsequent Heat Treatment	Proportional Limit, psi	Yield Strength, psi	Tensile Strength, psi	Elongation in 2 in., percent
301.. . .	As received	None	18 000	31 000	102 000	72.0
	10% at R.T.	None 550 F.—24 hr.	19 000 21 000	78 000 86 000	120 000 119 500	44.5 46.5*
	10% at -105 F.	None 550 F.—24 hr.	21 000 24 000	84 000 86 000	153 000 142 000	32.5 40.0
	10% at -320 F.	550 F.—24 hr.	26 000	95 000	153 000	31
	20% at R.T.	None 550 F.—24 hr.	21 000 26 000	96 000 117 000	139 500 146 000	32 33
	20% at -105 F.	None 550 F.—24 hr.	22 000 45 000	128 000 159 000	206 000 193 500	18.5 15.5
	20% at -320 F.	None 550 F.—24 hr.	33 000 42 000	182 000 218 000	236 000 241 000	10 5.5
	40% at R.T.	None 550 F.—24 hr.	32 000 33 000	156 000 166 000	186 000 191 000	9 8.5
	40% at -105 F.	None 550 F.—24 hr.	122 000 157 000	268 000 275 000	273 000 276 000	3.5 2
	40% at -320 F.	None 550 F.—24 hr.	163 000 236 000	291 000 308 000	295 000 307 000	3.3 3
	60% at R.T.	None 550 F.—24 hr.	45 000 59 000	209 000 216 000	216 000 242 000	3 2
	60% at -105 F.	None 550 F.—24 hr.	172 000 185 000	311 000 313 000	318 000 316 000	1.5 1.5
302A.....	As received	None	23 000	38 000	90 000	58
	16% at -105 F.	None 550 F.—24 hr.	26 000 31 000	97 000 97 000	119 000 131 500	26 27
	20% at R.T.	None 550 F.—24 hr.	30 000 33 000	105 000 102 000	124 500 121 000	27 28.5
	20% at -320 F.	None 550 F.—24 hr.	27 000 34 000	124 000 143 000	189 000 186 000	15.5 11
	40% at R.T.	None 550 F.—24 hr.	46 000 48 000	141 000 155 000	162 500 172 000	8.5 8.5
	40% at -105 F.	None 550 F.—24 hr.	49 000 63 000	192 000 221 000	225 000 236 000	3.5 3.5
	40% at -320 F.	None 550 F.—24 hr.	52 000 59 000	227 000 255 000	250 000 260 000	4 2.5
	60% at R.T.	None 550 F.—24 hr.	57 000 58 000	166 000 187 000	189 000 202 000	3.5 3.5
	60% at -105 F.	None 550 F.—24 hr.	75 000 97 000	259 000 273 000	264 000 280 000	1.5 1
	60% at -320 F.	None 550 F.—24 hr.	99 000 100 000	295 000 306 000	299 000 307 000	1.5 1.5
304.....	60% at R.T.	None 550 F.—24 hr.	58 000 64 000	161 500 182 000	192 000 200 500	5.0 3.0
	60% at -320 F.	None 550 F.—24 hr.	57 500 55 500	273 000 266 000	278 000 297 000	1.5 1.5
347.. . .	60% at R.T.	None 800 F.—1 hr.	35 000 50 500	141 000 160 000	169 000 177 000	3.5 5.0
	60% at -320 F.	None 800 F.—1 hr.	68 500 52 500	202 000 217 000	214 000 292 000	3.0 2.0

<sup>a</sup> R.T. = room temperature.

DATA FROM INTERNATIONAL NICKEL COMPANY

COLLINS, EZEKIEL, SEPP, AND RIZIKA

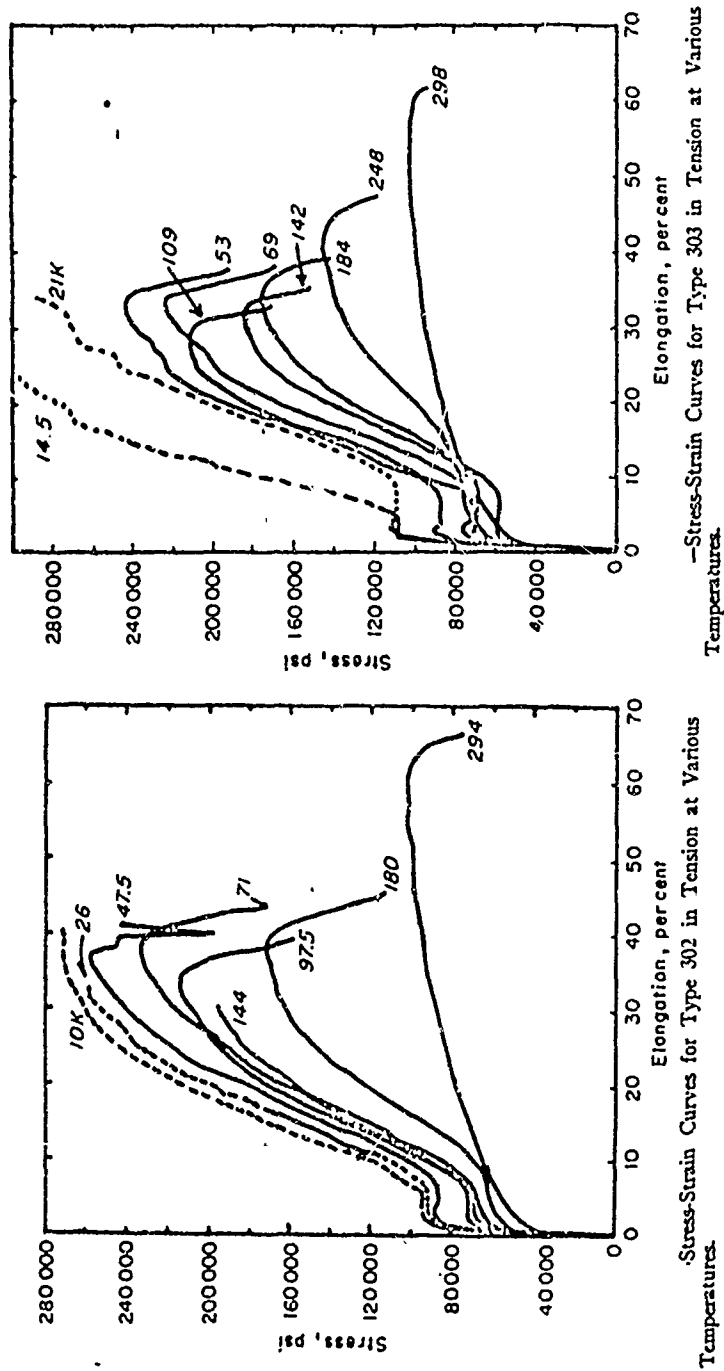
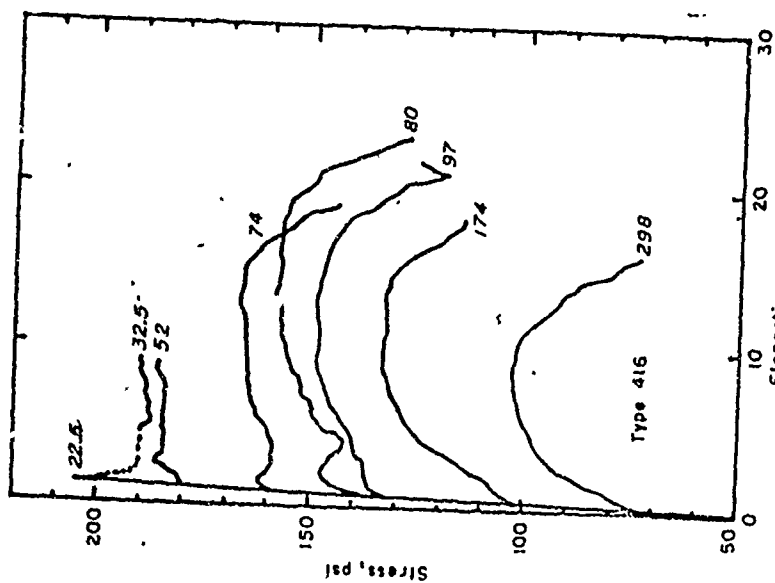
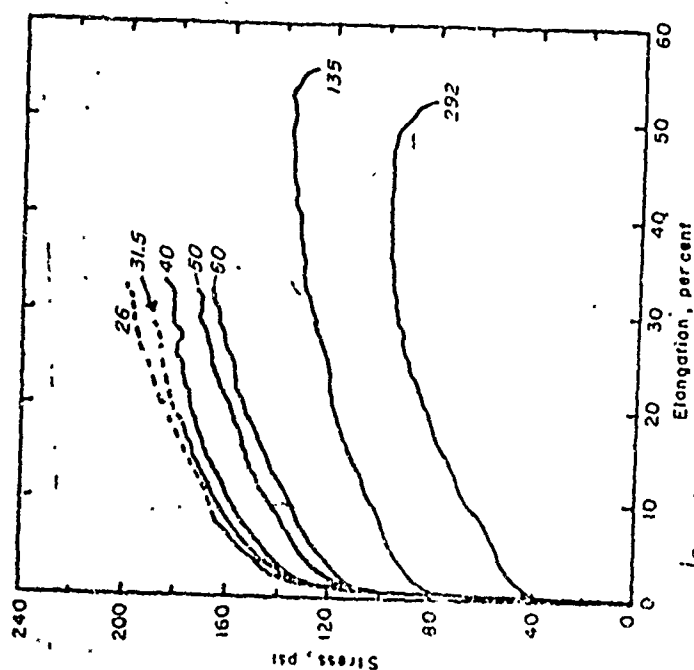


FIGURE 19

# ON STEELS AT LOW TEMPERATURE



—Stress-Strain Curves for Type 416 in Tension at Various Temperatures.



—Stress-Strain Curves for Type 310 in Tension at Various Temperatures

FIGURE 20

Pages 11  
 FW-11  
 Model 7  
 DATE: 8 December 1968

TABLE XVII  
 Low Temperature Impact Properties of Low Carbon 3½% and 5% Nickel Steels

Type	Chemical Analysis					Impact, Ft. Lbs (Charpy, Keyhole Notch)					
	% C	% Mn	% Si	% Ni	% Mo	70° F.	-100° F.	-210° F.	-265° F.	-290° F.	-320° F.
3½% Ni....	0.09	0.36	0.13	3.77	...	56 to 58	45 to 55	29 to 33	23 to 24	2 to 8	...
5% Ni....	0.09	0.37	0.13	5.00	...	55 to 56	47 to 53	33	25 to 29	11 to 22	5 to 6
5% Ni....	0.03	0.51	0.18	5.04	...	80 to 85	74 to 75	55 to 63	48 to 58	7 to 18	3 to 4
2¼% Ni Mo	0.09	0.34	0.11	2.77	0.31	62 to 64	55 to 58	29 to 39	12 to 13	5	...
*5% Ni Mo.	0.09	0.86	0.22	5.35	0.34	...	...	...	6	...	...
*4½% Ni...	0.14	0.38	0.25	4.26	...	...	...	22 to 24	13 to 22	7 to 15	3 to 4

\* Commercial melts.

Tensile Test Results for Experimental 3½% and 5% Nickel Steels

Steel	Tensile Strength p.s.i.	Yield Point p.s.i.	Proportional Limit p.s.i.	Elongation in 2 in., %	Red. of Area, %	Brinell
0.09 C—3.77 Ni.....	67,200	53,500	51,100	37.0	70.6	133
.09 C—5.00 Ni.....	72,000	59,600	55,800	36.5	71.0	147
.03 C—5.04 Ni.....	67,400	58,200	55,600	40.0	80.8	140

Effect of Reheating Temperature on the Impact Properties of 8½% Nickel Steel

Treatment	Charpy Impact, Ft. Lbs. (Keyhole Notch)	
	Room Temperature	-320° F.
Double normalized.....	31 to 38	17 to 20
Double normalized, reheated 800° F.....	32 to 34	6
Double normalized, reheated 900° F.....	42 to 48	17 to 21
Double normalized, reheated 1050° F.....	49 to 51	26 to 29
Double normalized, reheated 1150° F.....	52 to 62	9 to 12
Double normalized, reheated 1050° F. and redrawn 800° F.....	73 to 84	31 to 38

DATA FROM INTERNATIONAL NICKEL COMPANY

## Composition and Heat Treatment of Steels Tested

Type	Size of Section Treated	Chemical Analyses				Heat Treatment (°F.)
		% C	% Mn	% Ni	% Cr	
3½% Ni	1" rounds	0.15	0.45	3.43	—	1650 A.C., 1450 A.C., 1200 A.C.
8½% Ni	½" plate	0.11	0.26	8.35	—	1650 A.C., 1450 A.C., 1050 A.C.
18-8	1" rounds	0.06	—	9.79	17.87	1800 Water Quenched.

A.C. = Air Cooled.

## Charpy Impact, Ft. Lbs.—Before and After Exposure to Liquid Nitrogen

Conditions		Steels		
		3½% Nickel	8½% Nickel	18-8
Tested at 70° F.	No aging, no chilling.....	60, 57	50, 51	80, 90
	No aging, chilled -320° F..	57, 59	43, 44	90, 91
	Aged 6 mos. at 70° F., no chilling.....	56, 62	53, 50	96, 97
	Aged 6 mos. at -320° F....	59, 60	42, 43	91, 83
	Aged 12 mos. at 70° F., no chilling.....	63, 56	50, 52	93, 92
	Aged 12 mos. at -320° F....	57, 58	44, 43	89, 83
	Tested at -200° F.			
	No aging.....	11, 13*	25, 24	72, 73
Tested at -320° F.	Aged at -320° F., 6 mos....	15, 22, 13*	26, 22, 24	72, 74, 75
	Aged at -320° F., 12 mos..	13, 21, 21*	23, 23, 23	73, 77, 74

\*Tested at -200° F.

## Charpy Impact, Ft. Lbs., of Welded Specimens

Conditions		Material		
		8½% Nickel welded with 25-20, notched in weld	8½% Nickel welded with 25-20, notched in fusion zone	18-8 welded with 18-8, notched in weld
Tested at 70° F.	No aging, no chilling.....	24, 25	28, 39	28, 28
	No aging, chilled -320° F..	27, 30	53, 31	31, 33
	Aged 6 mos. at 70° F., no chilling.....	31, 29	36, 50	26, 23
	Aged 6 mos. at -320° F....	25, 30	50, 29	35, 26
	Aged 12 mos. at 70° F., no chilling.....	24, 28	46, 42	35, 31
	Aged 12 mos. at -320° F.,	28, 33	35, 40	28, 29
	Tested at -320° F.			
	No aging.....	26, 19, 27	22, 30, 28	18, 18
Tested at -320° F.	Aged -320° F., 6 mos....	20, 16, 17	28, 20, 32	22, 22, 17
	Aged -320° F., 12 mos....	27, 21, 18	26, 27, 24	22, 19, 17

DATA FROM INTERNATIONAL NICKEL COMPANY

Data from NBS Report 5024,  
 by Kropschot and Graham.

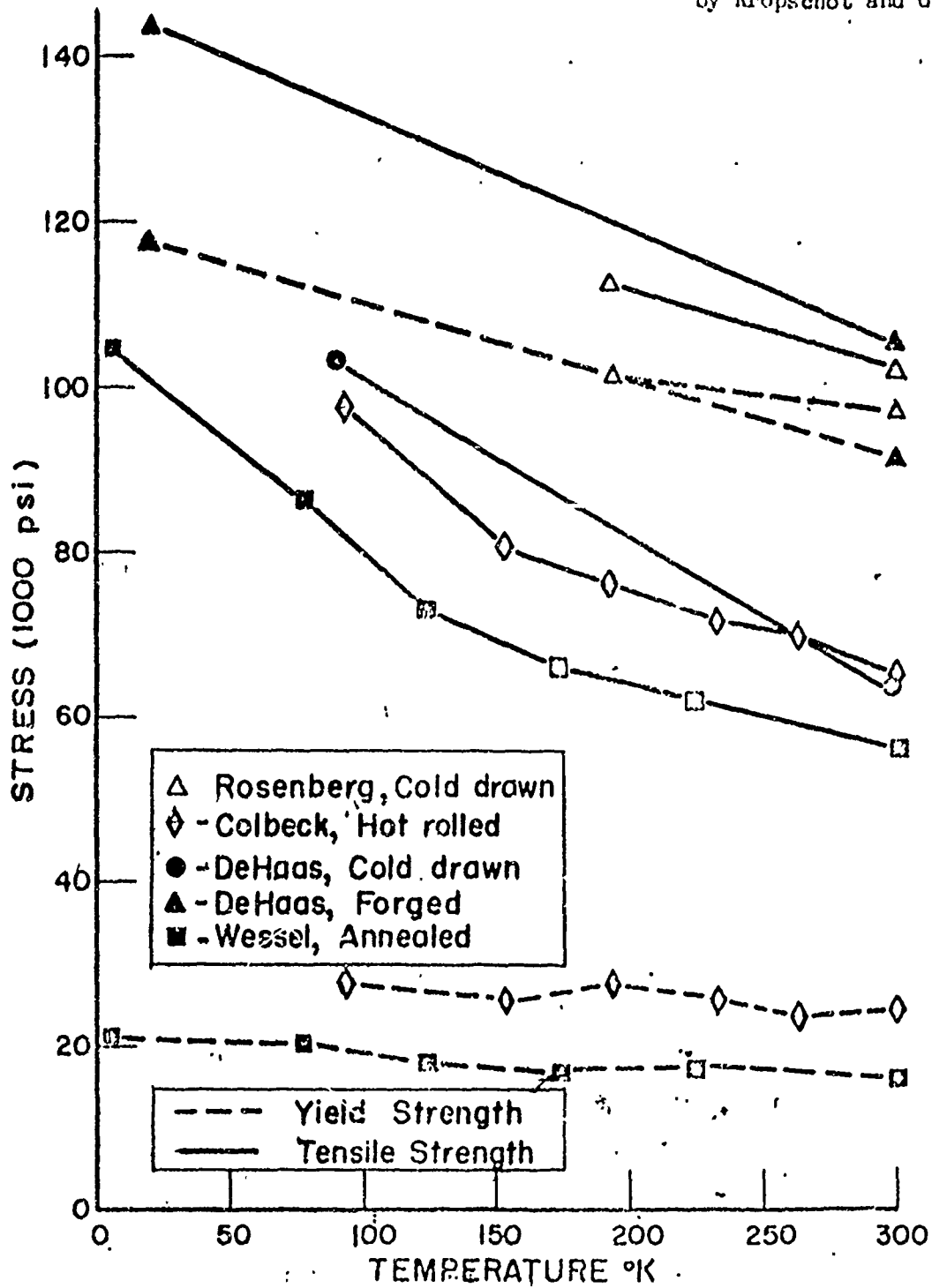


Figure 21. Tensile and Yield Strength of Nickel.

Data from NBS Report No. 5024,  
 by K. Oschot and Graham

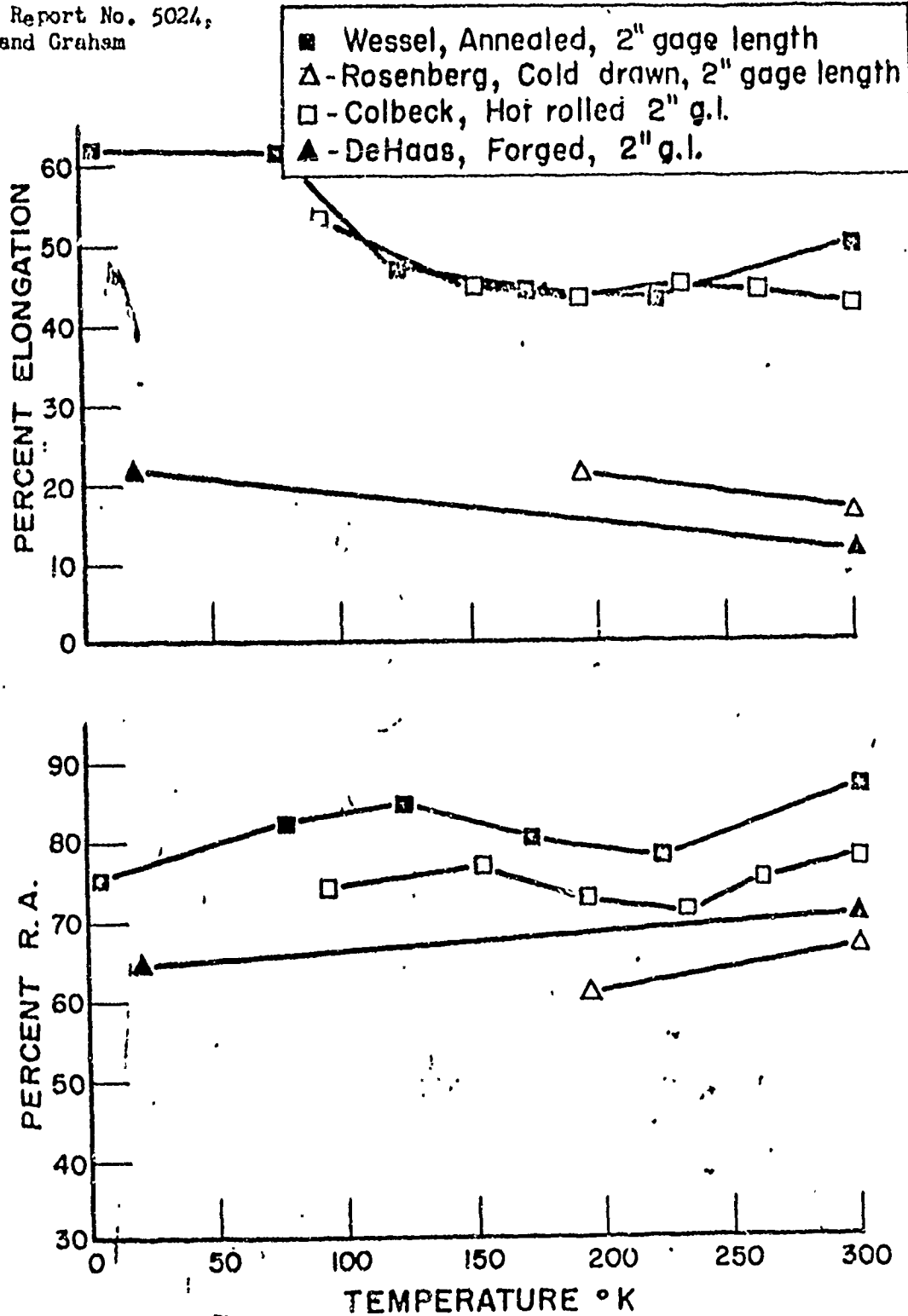


Figure 22 Elongation and Reduction of Area of Nickel.

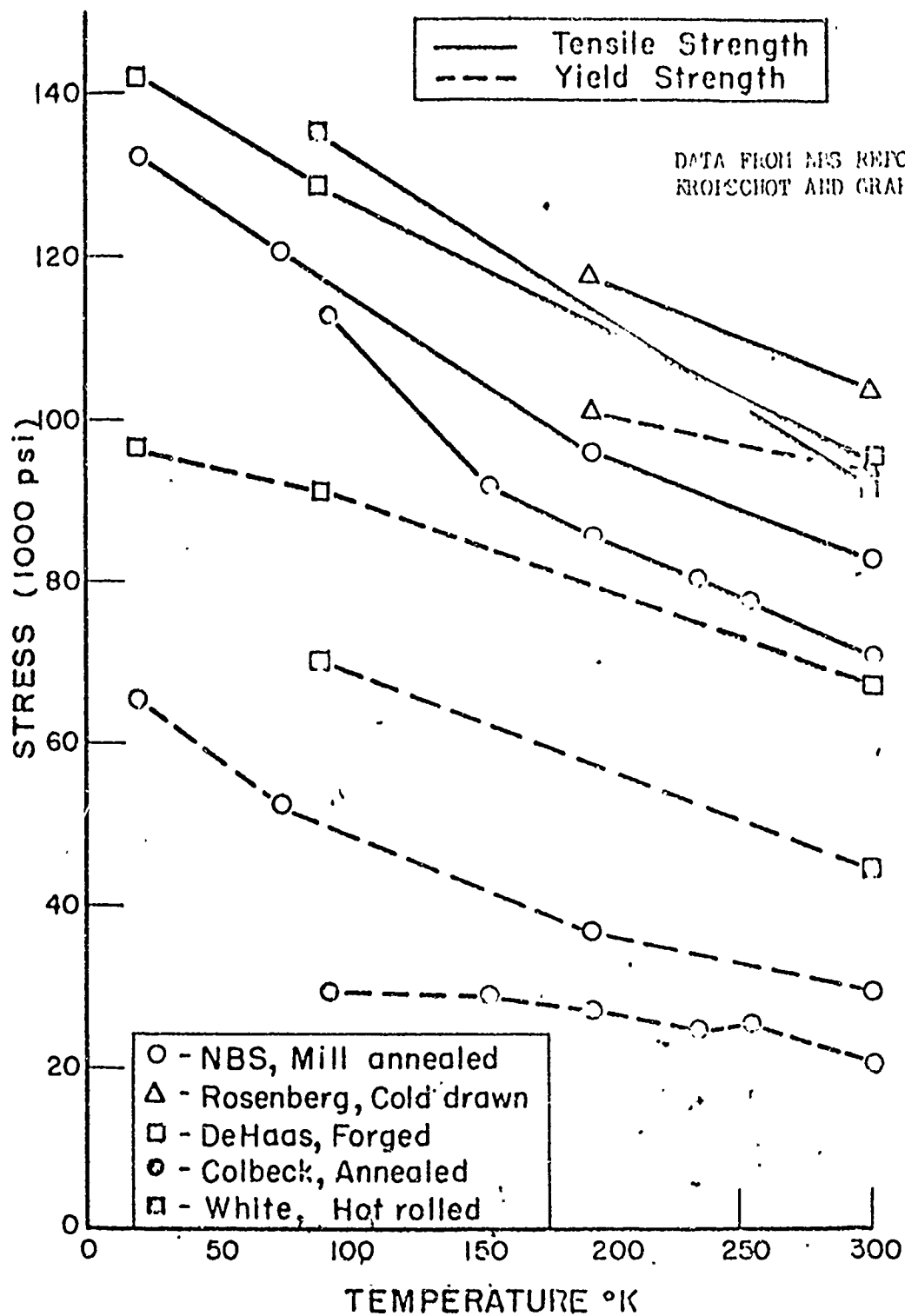


Figure 23 Tensile and Yield Strength of Monel.

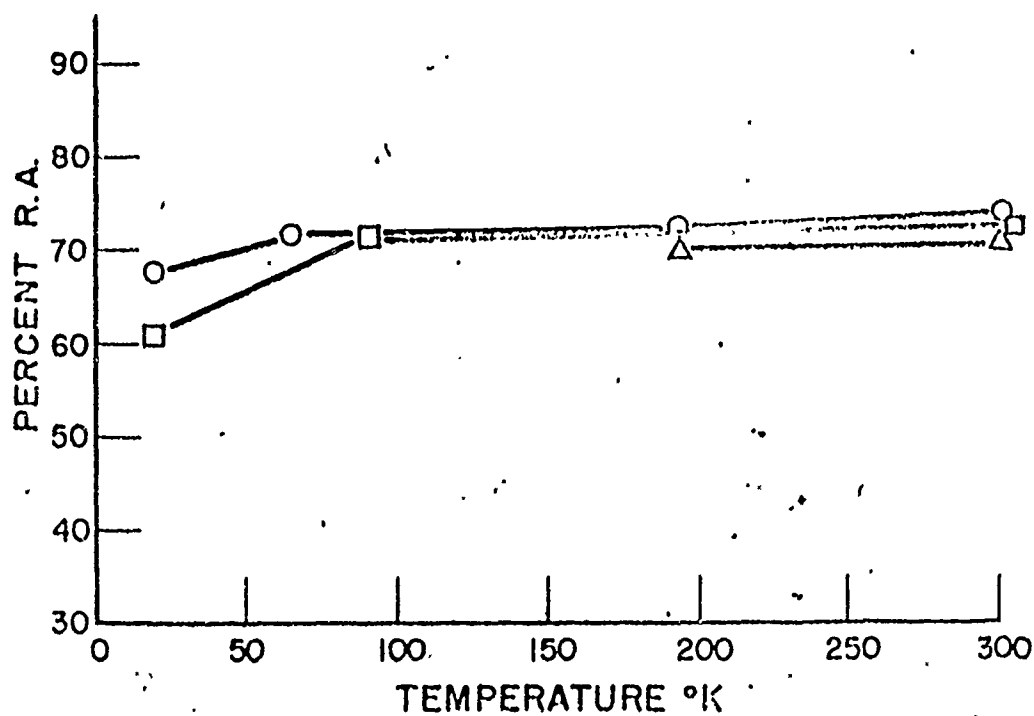
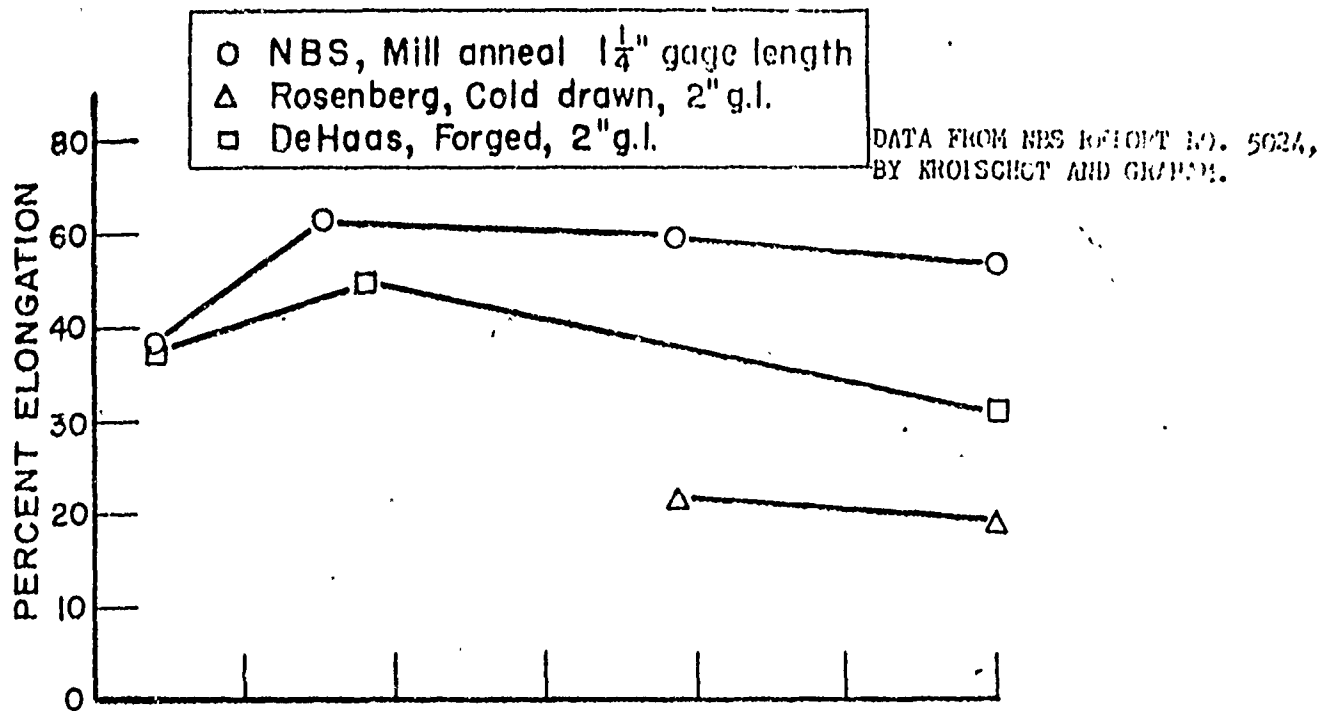


Figure 24 Elongation and Reduction in Area of Monel

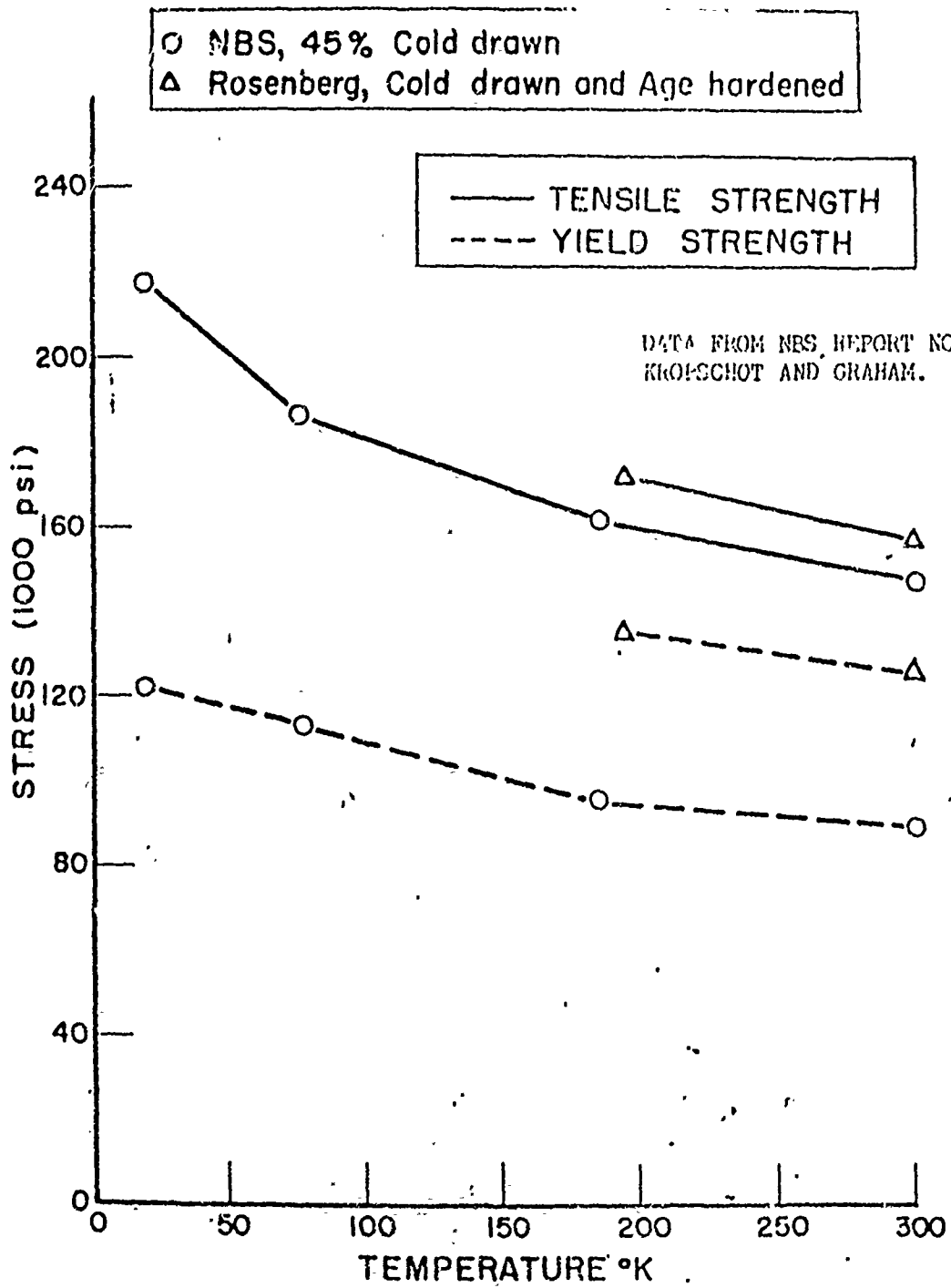


Figure 25 Tensile and Yield Strength of "K" Monel.

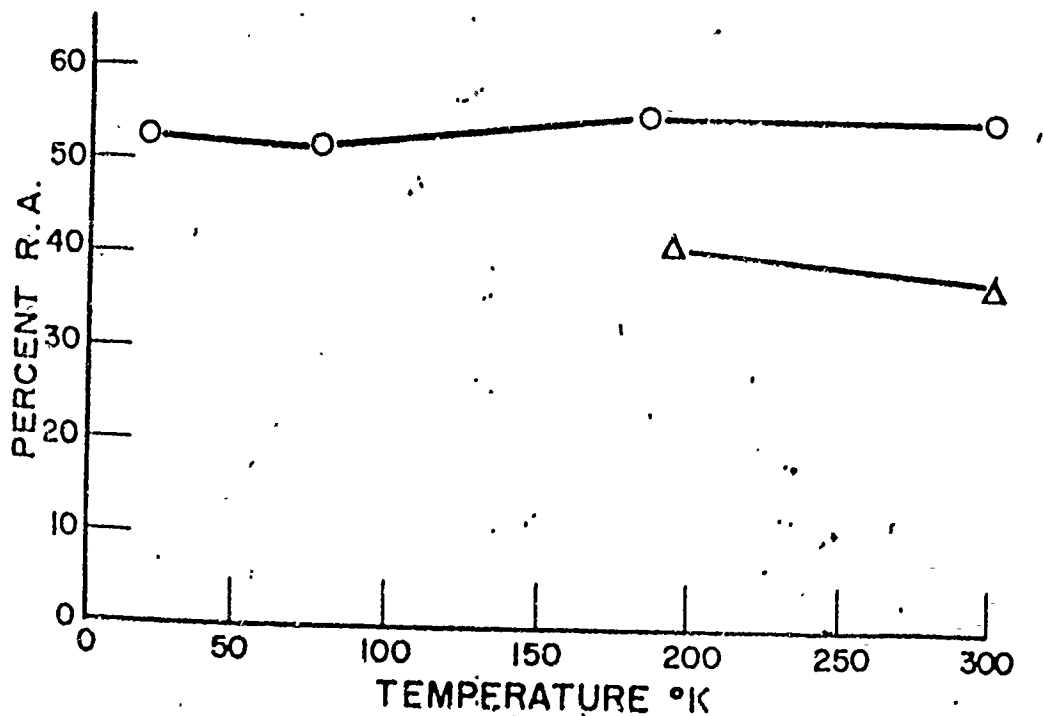
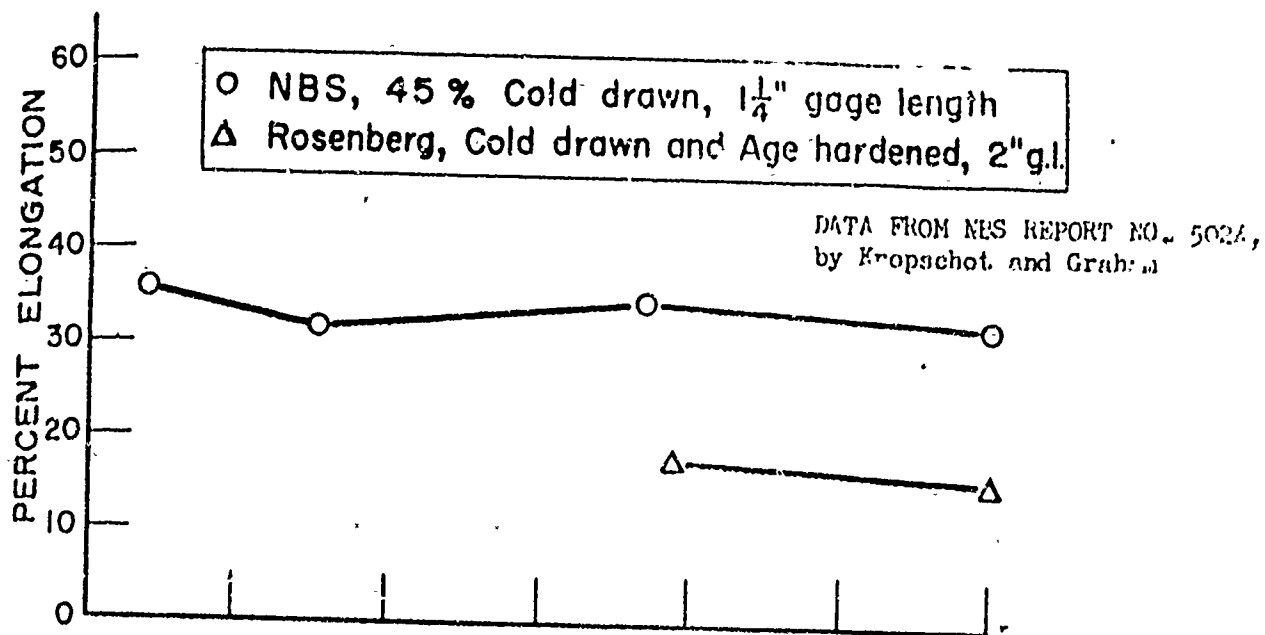


Figure 25 Elongation and Reduction of Area of "K" Monel.

DATA FROM NBS REPORT NO. 5077,  
BY KROSGRANT AND GRAHAM.

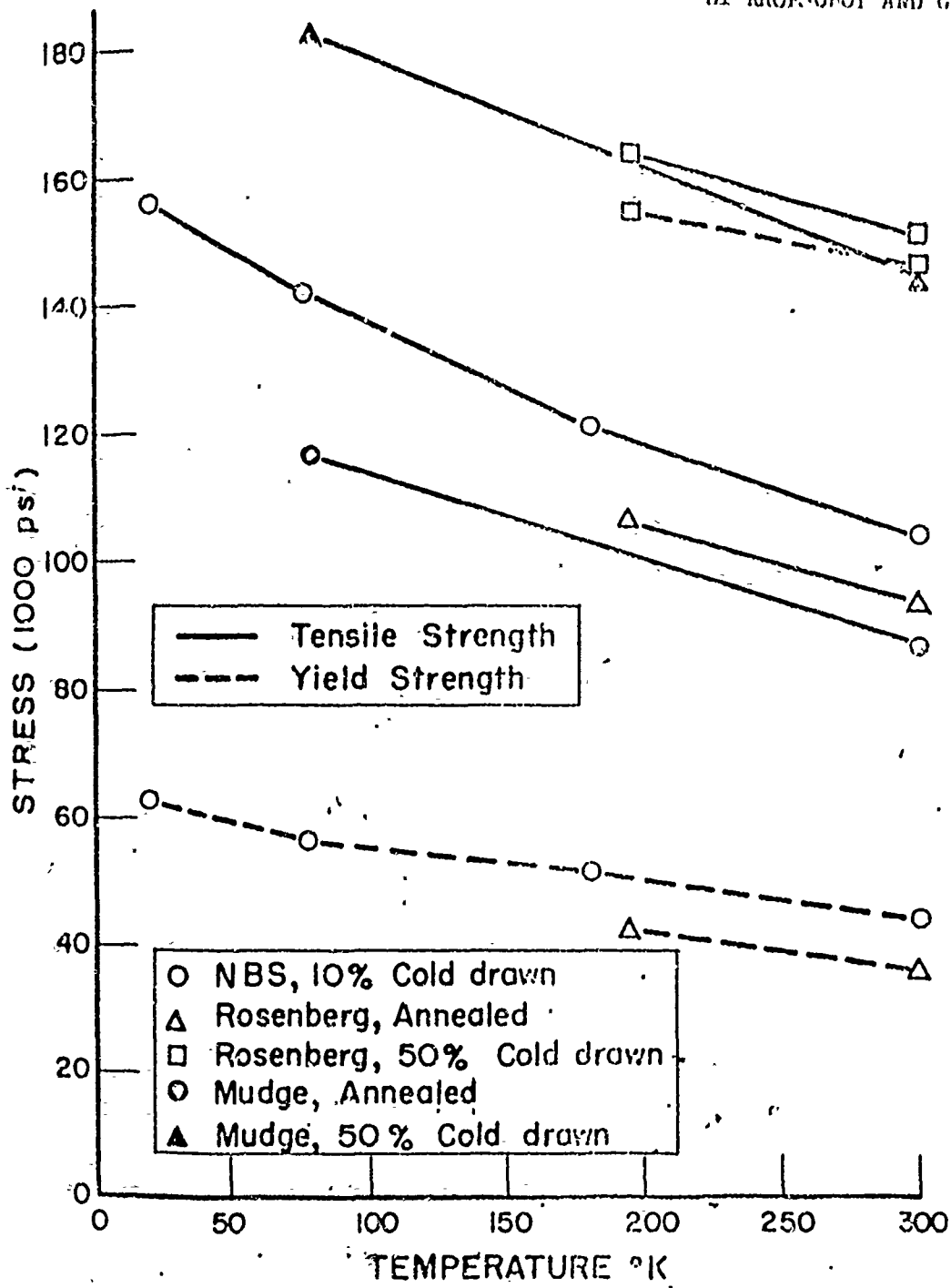


Figure 27 Tensile and Yield Strength of Inconel.

Data from RRS Report No. 5627, by J. A. Graham and Graham.

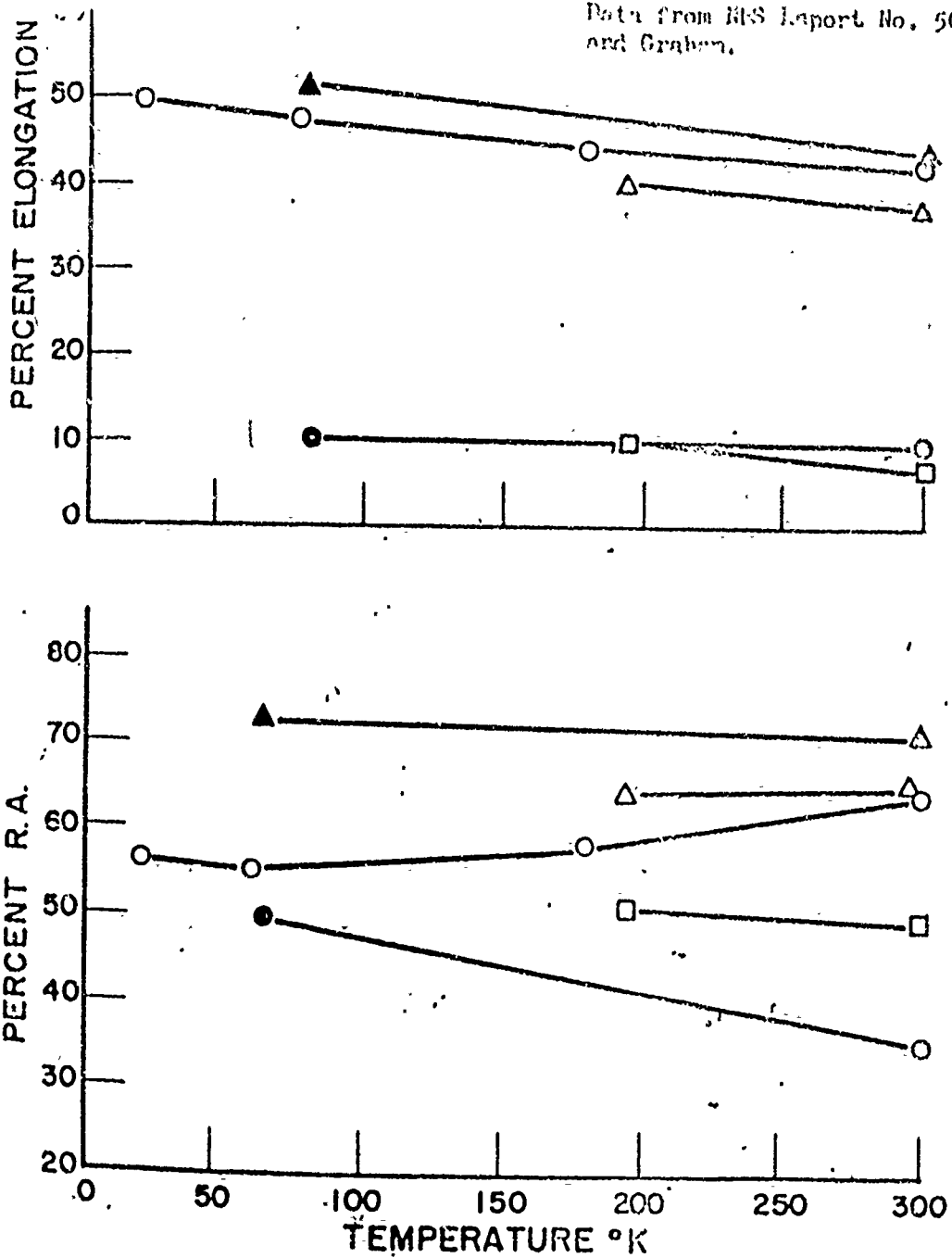


Figure 28 Elongation and Reduction of Area of Inconel.

Data from HFS Report No. 5024, by Frenkel and Graham.

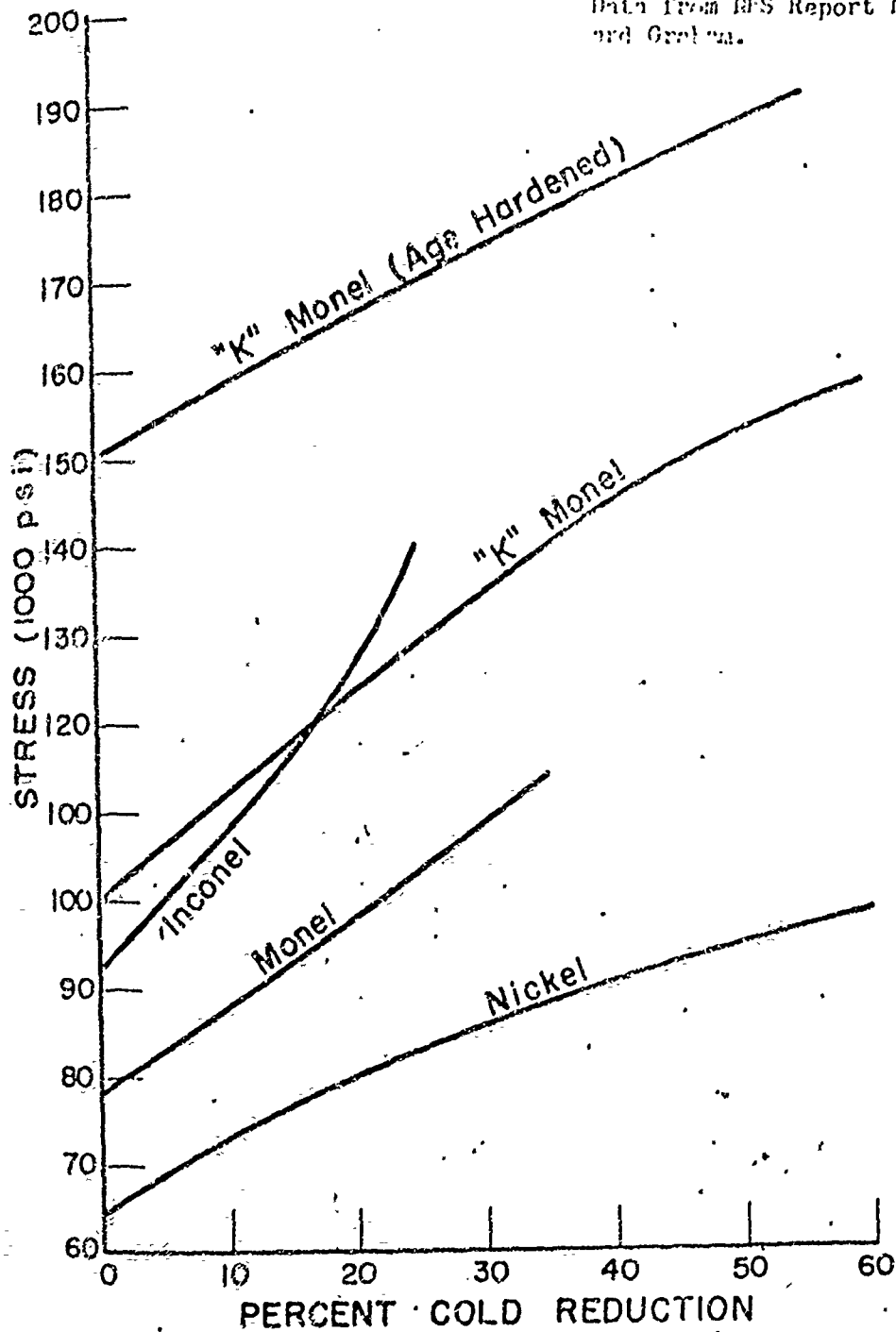


Figure 29. Effect of Cold Work upon the Tensile Strength of Nickel and the Nickel Alloys. Reference 7, 8, 9, 10.

### NICKEL

Condition	Impact Energy, ft-lbs			Specimen	Reference
	300°K	195°K	80°K to 90°K		
Annealed	216	235	234	Charpy-V	White
Annealed	90	92	98	Izod	Colbeck
Hot Rolled	195	236	227	Charpy-V	White
Cold Drawn	185	205	210	Charpy-V	White
Cold Drawn	204	216	---	Charpy-V	Rosenberg

### MONEL

Condition	Impact Energy, ft-lbs			Specimen	Reference
	300°K	195°K	80°K to 90°K		
Annealed	182	178	---	Charpy-V	Rosenberg
Annealed	216	218	212	Charpy-V	White
Annealed	90	90	97	Izod	Colbeck
Hot Rolled	219	213	196	Charpy-V	White
Forged	216	---	216	Charpy-V	Mudge
Cold Drawn	62	---	63	Charpy-K	White

### "K" MONEL

Condition	Impact Energy, ft-lbs			Specimen	Reference
	300°K	195°K	80°K to 90°K		
Age Hardened	27	27	---	Charpy-V	Rosenberg

### INCONEL

Condition	Impact Energy, ft-lbs			Specimen	Reference
	300°K	195°K	80°K to 90°K		
Annealed	182	178	---	Charpy-V	Rosenberg
Annealed	213	---	169	Charpy-V	Mudge
Hot Rolled	236	206	187	Charpy-V	White
Cold Drawn	69	---	61	Charpy-V	Mudge
Cold Drawn	53	59	---	Charpy-V	Rosenberg

TABLE XIX- Impact Strength of Nickel and the Nickel Alloys.

DATA FROM NBS REPORT NO. 5021, BY  
 KHOPSCHOT AND GRAF

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Model 7

DATE: 8 December 1953

DATA FROM NBS REPORT 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 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2177. 2178. 2179. 2180. 2181. 2182. 2183. 2184. 2185. 2186. 2187. 2188. 2189. 2190. 2191. 2192. 2193. 2194. 2195. 2196. 2197. 2198. 2199. 2200. 2201. 2202. 2203. 2204. 2205. 2206. 2207. 2208. 2209. 2210. 2211. 2212. 2213. 2214. 2215. 2216. 2217. 2

Some Mechanical Properties of Nickel Alloys at Low Temperatures

Material	Condition	Temp. °F.	Yield Strength % of offset psi.	Tensile Strength psi.	Elongation 1 in 2 in.	Reduction of Area %	Hardness Rockwell	Charpy Impact Strength ft.-lb.
Nickel	Hot-rolled	Room	24,600	65,600	50.0	-	-	-
	"	-112	27,500	76,400	-	-	-	-
	"	-292	20,000	98,000	-	-	-	-
	"	-310	-	105,000	51.0	-	-	-
	Cold-drawn	Room	97,400	103,400	16.3	66.9	19C	-
	"	-110	101,800	112,300	21.5	60.9	22C	-
	As cast	Room	27,600	64,200	25.0	29.0	111 BHN	35
	"	-110	-	-	-	-	-	37
	"	-210	-	-	-	-	-	41
	"	-320	-	-	-	-	-	38
Monel	Weld metal	Room	-	-	-	-	-	40
	"	-320	-	-	-	-	-	35
	Annealed	Room	31,500	70,650	51.5	79.0	-	189-216
	"	-297	49,500	119,250	49.5	73.9	-	184-212
	Forged	Room	67,000	92,000	31.0	72.7	-	216
	"	-297	91,500	128,250	44.5	71.8	-	216
	"	-423	96,400	142,000	38.5	61.0	-	-
	Cold-drawn	Room	93,700	103,800	19.0	71.0	19C	101
	"	-110	100,850	117,450	21.6	70.2	25C	178
	Cold-drawn, annealed	Room	29,900	82,700	46.2	74.0	-	-
Monel	"	-112	36,750	95,300	49.5	72.2	-	-
	"	-323	52,300	120,400	51.4	71.0	-	-
	"	-423	65,400	132,100	38.1	67.7	-	-
	As cast	Room	22,675	79,000	35.8	61.3	-	74
	"	32	22,750	81,200	36.3	64.8	-	91
	"	-40	23,500	86,650	35.7	67.4	-	-
	"	-112	26,150	89,600	36.5	67.5	-	-
	"	-310	-	-	-	-	-	91
	Weld metal	Room	-	-	-	-	-	78
	"	-310	-	-	-	-	-	73
"H" Monel	As cast	Room	64,900	103,000	22.5	26.4	192 BHN	50
	"	32	-	-	-	-	-	50
	"	-110	-	-	-	-	-	54
	"	-210	-	-	-	-	-	49
"S" Monel	"	-310	-	-	-	-	-	48
	As cast	Room	116,700	142,700	2	2	36C	5
	"	-110	-	-	-	-	-	5
	"	-210	-	-	-	-	-	5
"K" Monel	"	-320	-	-	-	-	-	5
	Cold-drawn, age-hardened	Room	125,900	157,300	15.5	37.4	33C	27
	"	-110	134,600	171,550	17.3	41.1	36C	27
	Annealed	Room <sup>b</sup>	50,000	100,000	10.0	60.0	-	-
	"	-300	53,950	124,400	53.0	66.0	-	-
	Annealed, age-hardened	Room <sup>b</sup>	100,000	140,000	25.0	40.0	-	-
	"	-300	112,400	177,150	19.0	52.1	-	-
	Hot-finished	Room <sup>b</sup>	50,000	110,000	40.0	60.0	-	-
	"	-300	61,800	132,900	57.0	73.0	-	-
	Hot-finished, age-hardened	Room <sup>b</sup>	110,000	150,000	25.0	40.0	-	-
	"	-300	130,400	191,950	15.5	42.1	-	-
	Cold-drawn	Room <sup>b</sup>	90,000	120,000	30.0	52.0	-	-
	"	-300	136,650	158,500	30.5	55.8	-	-
	Cold-drawn, age-hardened	Room <sup>b</sup>	120,000	160,000	20.0	35.0	-	-
	"	-300	160,200	202,000	27.0	47.3	-	-
	Welded	Room <sup>b</sup>	45,000	95,000	25.0	30.0	-	-
Inconel	"	-300	67,000	126,000	29.0 <sup>a</sup>	31.4	-	-
	Welded, age-hardened	Room <sup>b</sup>	90,000	125,000	10.0	20.0	-	-
	"	-300	118,100	159,000	15.0 <sup>a</sup>	27.3	-	-
	Annealed	Room	36,800	93,800	17.3	64.1	82B	236
	"	-110	42,400	106,400	33.8	64.0	87B	206
	"	-310	-	-	-	-	-	167
	Cold-drawn	Room	147,700	192,100	7.0	49.3	31C	69
	"	-110	154,900	163,900	9.8	51.2	36C	-
	"	-310	-	-	-	-	-	61 (315°F.)
	"	Room	-	145,000	10.0	35.1	-	-
	"	-315	-	182,000	10.0	49.5	-	-
	Hot-rolled	Room	-	87,000	4.5	71.9	-	213
	"	-315	-	116,750	61.0	72.7	-	169
	As cast	Room	43,400	75,700	10.0	16.2	160 BHN	74
	"	-110	-	-	-	-	-	19
	"	-210	-	-	-	-	-	19
Inconel "X"	"	-320	-	-	-	-	-	18
	Weld metal	Room	-	-	-	-	-	36
	"	-320	-	-	-	-	-	35
Inconel "X"	Age-hardened	Room	120,000	180,000	25.0	-	36C	33
	"	-109	-	-	-	-	-	36
	"	-320	-	-	-	-	-	37

<sup>a</sup> - Fracture in weld      <sup>b</sup> - Nominal values

Data from International Nickel Company.

## SUB-ZERO TENSILE TESTS

## FOR SEVERAL HIGH TEMPERATURE ALLOYS

TABLE XX

Alloy	Heat No.	Condition	Test Temp (°F)	0.2% Offset Yield Strength (psi)	Ultimate Strength (psi)	Elong. in 2" (%)	Red. of Area (%)	Ex10 <sup>-6</sup>
V-36	9X-317 <sup>S</sup>	2250°F-1 hr-WQ+	-100	107,060	161,630	6.0	--	35.0
"	"	1600°F-16 hrs-AC	"	120,730	179,330	7.5	--	34.3
"	"	"	-320	165,300	200,760	1.5	--	33.9
"	"	"	"	155,520	187,630	3.0	--	35.4
S-816	81112	2250°F-1 hr-WQ+	-100	85,120	148,770	14.5	12.0	32.0
"	"	1400°F-16 hrs-AC	"	82,370	149,020	19.0	15.0	34.7
"	"	"	-320	109,830	170,490	8.5	9.0	34.9
"	"	"	"	112,180	169,390	9.0	10.0	34.7
AF-183	9X-110	1900°F-1 hr-WQ+	-100	111,130	174,780	10.0	8.0	27.3
"	"	1300°F-16 hrs-AC	"	109,390	174,290	11.5	8.0	30.8
"	"	"	-320	164,000	215,560	2.5	2.0	28.1
A-286	6X-507	1800°F-1 hr-WQ+	-100	117,100	177,020	30.5	50.0	28.6
"	"	1325°F-16 hrs-AC	"	117,820	177,730	30.0	49.0	28.2
"	"	"	-320	127,550	209,430	36.0	--	29.0
"	"	"	"	129,880	208,680	33.5	47.0	30.2
A-286	6X-507	1650°F-1 hr-WQ+	-100	--	176,980	30.0	50.0	--
"	"	1325°F-16 hrs-AC	-320	127,310	209,430	36.5	--	28.6

(s) Sheet material

TABLE XX (Continued)

Alloy	Heat No.	Condition	Test Temp. (°F)	0.2% Offset Yield Strength (psi)	Ultimate Strength (psi)	Elong. in 2" (%)	Red. of Area (%)	Ex10-6
D-979	21737	1850°F-1 hr-QQ+	-100	152,270	214,680	16.0	20.0	31.5
"	"	1550°F-4 hr-AC+	"	153,520	215,430	14.5	16.5	31.2
"	"	1300°F-16 hrs-AC						
"	"	"	-320	168,750	237,650	12.0	13.0	32.5
"	"	"	"	169,250	233,150	11.5	9.3	31.8
AF-71	83845	2050°F-1 hr-WQ+	-100	131,800	169,750	5.0	4.0	26.0
"	"	1325°F-32 hrs-AC	"	123,560	176,730	14.5	13.0	28.2

Allegheny Ludlum Steel Corp.  
Research Department  
Watervliet, New York  
June 24, 1958

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EMG-44  
Model 7  
DATE: 8 Dec 1958

Office - 110 West  
Data from Aluminum Company of America

Table II. Tensile Properties of Nonheat-Treatable Wrought Aluminum Alloys at Low Temperatures

Commercial Alloy & Temper	Tensile Strength (psi)	Yield Strength (psi)	100° F		-100° F		Reduction of Area (%)	Elongation in 2 in. of Area (%)	Tensile Strength at 2 in. of Area (psi)	Reduction of Area (%)
			Yield Strength (psi)	Elongation in 2 in. of Area (%)	Yield Strength (psi)	Elongation in 2 in. of Area (%)				
99.99% Al	10,000	6,000	10,000	31.0	10,000	28.5	80	53.0	23,200	50.0
99.95% Al	12,000	7,000	12,000	28.5	12,000	26.0	80	50.0	25,000	45.0
99.90% Al	14,000	8,000	14,000	26.0	14,000	23.5	75	47.5	26,800	40.0
99.85% Al	16,000	9,000	16,000	23.5	16,000	21.0	70	45.0	28,600	35.0
99.80% Al	18,000	10,000	18,000	21.0	18,000	18.5	65	42.5	30,400	30.0
99.75% Al	20,000	11,000	20,000	18.5	20,000	16.0	60	40.0	32,200	25.0
99.70% Al	22,000	12,000	22,000	16.0	22,000	13.5	55	37.5	34,000	20.0
99.65% Al	24,000	13,000	24,000	13.5	24,000	11.0	50	35.0	35,800	15.0
99.60% Al	26,000	14,000	26,000	11.0	26,000	8.5	45	32.5	37,600	10.0
99.55% Al	28,000	15,000	28,000	8.5	28,000	6.0	40	30.0	39,400	5.0
99.50% Al	30,000	16,000	30,000	6.0	30,000	3.5	35	27.5	41,200	0.0
99.45% Al	32,000	17,000	32,000	3.5	32,000	1.0	30	25.0	43,000	-5.0
99.40% Al	34,000	18,000	34,000	1.0	34,000	-1.5	25	22.5	44,800	-10.0
99.35% Al	36,000	19,000	36,000	-1.5	36,000	-4.0	20	20.0	46,600	-15.0
99.30% Al	38,000	20,000	38,000	-4.0	38,000	-6.5	15	17.5	48,400	-20.0
99.25% Al	40,000	21,000	40,000	-6.5	40,000	-9.0	10	15.0	50,200	-25.0
99.20% Al	42,000	22,000	42,000	-9.0	42,000	-11.5	5	12.5	52,000	-30.0
99.15% Al	44,000	23,000	44,000	-11.5	44,000	-14.0	0	10.0	53,800	-35.0
99.10% Al	46,000	24,000	46,000	-14.0	46,000	-16.5	-5	7.5	55,600	-40.0
99.05% Al	48,000	25,000	48,000	-16.5	48,000	-19.0	-10	5.0	57,400	-45.0
99.00% Al	50,000	26,000	50,000	-19.0	50,000	-21.5	-15	2.5	59,200	-50.0
98.95% Al	52,000	27,000	52,000	-21.5	52,000	-24.0	-20	0.0	61,000	-55.0
98.90% Al	54,000	28,000	54,000	-24.0	54,000	-26.5	-25	-2.5	62,800	-60.0
98.85% Al	56,000	29,000	56,000	-26.5	56,000	-29.0	-30	-5.0	64,600	-65.0
98.80% Al	58,000	30,000	58,000	-29.0	58,000	-31.5	-35	-7.5	66,400	-70.0
98.75% Al	60,000	31,000	60,000	-31.5	60,000	-34.0	-40	-10.0	68,200	-75.0
98.70% Al	62,000	32,000	62,000	-34.0	62,000	-36.5	-45	-12.5	70,000	-80.0
98.65% Al	64,000	33,000	64,000	-36.5	64,000	-39.0	-50	-15.0	71,800	-85.0
98.60% Al	66,000	34,000	66,000	-39.0	66,000	-41.5	-55	-17.5	73,600	-90.0
98.55% Al	68,000	35,000	68,000	-41.5	68,000	-44.0	-60	-20.0	75,400	-95.0
98.50% Al	70,000	36,000	70,000	-44.0	70,000	-46.5	-65	-22.5	77,200	-100.0
98.45% Al	72,000	37,000	72,000	-46.5	72,000	-49.0	-70	-25.0	79,000	-105.0
98.40% Al	74,000	38,000	74,000	-49.0	74,000	-51.5	-75	-27.5	80,800	-110.0
98.35% Al	76,000	39,000	76,000	-51.5	76,000	-54.0	-80	-30.0	82,600	-115.0
98.30% Al	78,000	40,000	78,000	-54.0	78,000	-56.5	-85	-32.5	84,400	-120.0
98.25% Al	80,000	41,000	80,000	-56.5	80,000	-59.0	-90	-35.0	86,200	-125.0
98.20% Al	82,000	42,000	82,000	-59.0	82,000	-61.5	-95	-37.5	88,000	-130.0
98.15% Al	84,000	43,000	84,000	-61.5	84,000	-64.0	-100	-40.0	89,800	-135.0
98.10% Al	86,000	44,000	86,000	-64.0	86,000	-66.5	-105	-42.5	91,600	-140.0
98.05% Al	88,000	45,000	88,000	-66.5	88,000	-69.0	-110	-45.0	93,400	-145.0
98.00% Al	90,000	46,000	90,000	-69.0	90,000	-71.5	-115	-47.5	95,200	-150.0
97.95% Al	92,000	47,000	92,000	-71.5	92,000	-74.0	-120	-50.0	97,000	-155.0
97.90% Al	94,000	48,000	94,000	-74.0	94,000	-76.5	-125	-52.5	98,800	-160.0
97.85% Al	96,000	49,000	96,000	-76.5	96,000	-79.0	-130	-55.0	100,600	-165.0
97.80% Al	98,000	50,000	98,000	-79.0	98,000	-81.5	-135	-57.5	102,400	-170.0
97.75% Al	100,000	51,000	100,000	-81.5	100,000	-84.0	-140	-60.0	104,200	-175.0
97.70% Al	102,000	52,000	102,000	-84.0	102,000	-86.5	-145	-62.5	106,000	-180.0
97.65% Al	104,000	53,000	104,000	-86.5	104,000	-89.0	-150	-65.0	107,800	-185.0
97.60% Al	106,000	54,000	106,000	-89.0	106,000	-91.5	-155	-67.5	109,600	-190.0
97.55% Al	108,000	55,000	108,000	-91.5	108,000	-94.0	-160	-70.0	111,400	-195.0
97.50% Al	110,000	56,000	110,000	-94.0	110,000	-96.5	-165	-72.5	113,200	-200.0
97.45% Al	112,000	57,000	112,000	-96.5	112,000	-99.0	-170	-75.0	115,000	-205.0
97.40% Al	114,000	58,000	114,000	-99.0	114,000	-101.5	-175	-77.5	116,800	-210.0
97.35% Al	116,000	59,000	116,000	-101.5	116,000	-104.0	-180	-80.0	118,600	-215.0
97.30% Al	118,000	60,000	118,000	-104.0	118,000	-106.5	-185	-82.5	120,400	-220.0
97.25% Al	120,000	61,000	120,000	-106.5	120,000	-109.0	-190	-85.0	122,200	-225.0
97.20% Al	122,000	62,000	122,000	-109.0	122,000	-111.5	-195	-87.5	124,000	-230.0
97.15% Al	124,000	63,000	124,000	-111.5	124,000	-114.0	-200	-90.0	125,800	-235.0
97.10% Al	126,000	64,000	126,000	-114.0	126,000	-116.5	-205	-92.5	127,600	-240.0
97.05% Al	128,000	65,000	128,000	-116.5	128,000	-119.0	-210	-95.0	129,400	-245.0
97.00% Al	130,000	66,000	130,000	-119.0	130,000	-121.5	-215	-97.5	131,200	-250.0
96.95% Al	132,000	67,000	132,000	-121.5	132,000	-124.0	-220	-100.0	133,000	-255.0
96.90% Al	134,000	68,000	134,000	-124.0	134,000	-126.5	-225	-102.5	134,800	-260.0
96.85% Al	136,000	69,000	136,000	-126.5	136,000	-129.0	-230	-105.0	136,600	-265.0
96.80% Al	138,000	70,000	138,000	-129.0	138,000	-131.5	-235	-107.5	138,400	-270.0
96.75% Al	140,000	71,000	140,000	-131.5	140,000	-134.0	-240	-110.0	140,200	-275.0
96.70% Al	142,000	72,000	142,000	-134.0	142,000	-136.5	-245	-112.5	142,000	-280.0
96.65% Al	144,000	73,000	144,000	-136.5	144,000	-139.0	-250	-115.0	143,800	-285.0
96.60% Al	146,000	74,000	146,000	-139.0	146,000	-141.5	-255	-117.5	145,600	-290.0
96.55% Al	148,000	75,000	148,000	-141.5	148,000	-144.0	-260	-120.0	147,400	-295.0
96.50% Al	150,000	76,000	150,000	-144.0	150,000	-146.5	-265	-122.5	149,200	-300.0
96.45% Al	152,000	77,000	152,000	-146.5	152,000	-149.0	-270	-125.0	151,000	-305.0
96.40% Al	154,000	78,000	154,000	-149.0	154,000	-151.5	-275	-127.5	152,800	-310.0
96.35% Al	156,000	79,000	156,000	-151.5	156,000	-154.0	-280	-130.0	154,600	-315.0
96.30% Al	158,000	80,000	158,000	-154.0	158,000	-156.5	-285	-132.5	156,400	-320.0
96.25% Al	160,000	81,000	160,000	-156.5	160,000	-159.0	-290	-135.0	158,200	-325.0
96.20% Al	162,000	82,000	162,000	-159.0	162,000	-161.5	-295	-137.5	160,000	-330.0
96.15% Al	164,000	83,000	164,000	-161.5	164,000	-164.0	-300	-140.0	161,800	-335.0
96.10% Al	166,000	84,000	166,000	-164.0	166,000	-166.5	-305	-142.5	163,600	-340.0
96.05% Al	168,000	85,000	168,000	-166.5	168,000	-169.0	-310	-145.0	165,400	-345.0
96.00% Al	170,000	86,000	170,000	-169.0	170,000	-171.5	-315	-147.5	167,200	-350.0
95.95% Al	172,000	87,000	172,000	-171.5	172,000	-174.0	-320	-150.0	169,000	-355.0
95.90% Al	174,000	88,000	174,000	-174.0	174,000	-176.5	-325	-152.5	170,800	-360.0
95.85% Al	176,000	89,000	176,000	-176.5	176,000	-179.0	-330	-155.0	172,600	-365.0
95.80% Al	178,000	90,000	178,000	-179.0	178,000	-181.5	-335	-157.5	174,400	-370.0
95.75% Al	180,000	91,000	180,000	-181.5	180,000	-184.0	-340	-160.0	176,200	-375.0
95.70% Al	182,000	92,000	182,000	-184.0	182,000	-186.5	-345	-162.5	178,000	-380.0
95.65% Al	184,000	93,000	184,000	-186.5	184,000	-189.0	-350	-165.0	179,800	-385.0
95.60% Al	186,000	94,000	186,000	-189.0	186,000	-191.5	-355	-167.5	181,600	-390.0
95.55% Al	188,000	95,000	188,000	-191.5	188,000	-194.0	-360	-170.0	183,400	-395.0
95.50% Al	190,000	96,000	190,000	-194.0	190,000	-196.5	-365	-172.5	185,200	-400.0
95.45% Al	192,000	97,000	192,000	-196.5	192,000	-199.0	-370	-175.0	187,000	-405.0
95.40% Al	194,000	98,000	194,000	-199.0	194,000	-201.5	-375	-177.5	188,800	-410.0
95.35% Al	196,000	99,000	196,000	-201.5	196,000	-204.0	-380	-180.0	190,600	-415.0
95.30% Al	198,000	100,000	198,000	-204.0	198,000	-206.5	-385	-182.5	192,400	-420.0
95.25% Al	200									

Table III. Tensile Properties of Heat-Treatable Wrought Aluminum Alloys at Low Temperatures

Commercial Alloy & ASTM Designation	Tensile Strength (psi)	Yield Strength (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	Modulus of Elasticity (10 <sup>6</sup> psi)	Brinell Hardness	Rockwell C Hardness
1100	17,000	14,000	17.6	41	10,000	100	15
1100-H14	20,000	16,000	16.7	38	10,000	100	15
1100-H18	22,000	18,000	15.2	35	10,000	100	15
1100-H19	24,000	20,000	14.0	32	10,000	100	15
1100-H20	26,000	22,000	12.8	29	10,000	100	15
1100-H22	28,000	24,000	11.6	26	10,000	100	15
1100-H24	30,000	26,000	10.4	23	10,000	100	15
1100-H26	32,000	28,000	9.2	21	10,000	100	15
1100-H28	34,000	30,000	8.0	18	10,000	100	15
1100-H30	36,000	32,000	6.8	16	10,000	100	15
1100-H32	38,000	34,000	5.6	14	10,000	100	15
1100-H34	40,000	36,000	4.4	12	10,000	100	15
1100-H36	42,000	38,000	3.2	10	10,000	100	15
1100-H38	44,000	40,000	2.0	8	10,000	100	15
1100-H40	46,000	42,000	0.8	6	10,000	100	15
1100-H42	48,000	44,000	0.6	5	10,000	100	15
1100-H44	50,000	46,000	0.4	4	10,000	100	15
1100-H46	52,000	48,000	0.2	3	10,000	100	15
1100-H48	54,000	50,000	0.1	2	10,000	100	15
1100-H50	56,000	52,000	0.0	1	10,000	100	15
1100-H52	58,000	54,000	0.0	0	10,000	100	15
1100-H54	60,000	56,000	0.0	0	10,000	100	15
1100-H56	62,000	58,000	0.0	0	10,000	100	15
1100-H58	64,000	60,000	0.0	0	10,000	100	15
1100-H60	66,000	62,000	0.0	0	10,000	100	15
1100-H62	68,000	64,000	0.0	0	10,000	100	15
1100-H64	70,000	66,000	0.0	0	10,000	100	15
1100-H66	72,000	68,000	0.0	0	10,000	100	15
1100-H68	74,000	70,000	0.0	0	10,000	100	15
1100-H70	76,000	72,000	0.0	0	10,000	100	15
1100-H72	78,000	74,000	0.0	0	10,000	100	15
1100-H74	80,000	76,000	0.0	0	10,000	100	15
1100-H76	82,000	78,000	0.0	0	10,000	100	15
1100-H78	84,000	80,000	0.0	0	10,000	100	15
1100-H80	86,000	82,000	0.0	0	10,000	100	15
1100-H82	88,000	84,000	0.0	0	10,000	100	15
1100-H84	90,000	86,000	0.0	0	10,000	100	15
1100-H86	92,000	88,000	0.0	0	10,000	100	15
1100-H88	94,000	90,000	0.0	0	10,000	100	15
1100-H90	96,000	92,000	0.0	0	10,000	100	15
1100-H92	98,000	94,000	0.0	0	10,000	100	15
1100-H94	100,000	96,000	0.0	0	10,000	100	15
1100-H96	102,000	98,000	0.0	0	10,000	100	15
1100-H98	104,000	100,000	0.0	0	10,000	100	15
1100-H100	106,000	102,000	0.0	0	10,000	100	15
1100-H102	108,000	104,000	0.0	0	10,000	100	15
1100-H104	110,000	106,000	0.0	0	10,000	100	15
1100-H106	112,000	108,000	0.0	0	10,000	100	15
1100-H108	114,000	110,000	0.0	0	10,000	100	15
1100-H110	116,000	112,000	0.0	0	10,000	100	15
1100-H112	118,000	114,000	0.0	0	10,000	100	15
1100-H114	120,000	116,000	0.0	0	10,000	100	15
1100-H116	122,000	118,000	0.0	0	10,000	100	15
1100-H118	124,000	120,000	0.0	0	10,000	100	15
1100-H120	126,000	122,000	0.0	0	10,000	100	15
1100-H122	128,000	124,000	0.0	0	10,000	100	15
1100-H124	130,000	126,000	0.0	0	10,000	100	15
1100-H126	132,000	128,000	0.0	0	10,000	100	15
1100-H128	134,000	130,000	0.0	0	10,000	100	15
1100-H130	136,000	132,000	0.0	0	10,000	100	15
1100-H132	138,000	134,000	0.0	0	10,000	100	15
1100-H134	140,000	136,000	0.0	0	10,000	100	15
1100-H136	142,000	138,000	0.0	0	10,000	100	15
1100-H138	144,000	140,000	0.0	0	10,000	100	15
1100-H140	146,000	142,000	0.0	0	10,000	100	15
1100-H142	148,000	144,000	0.0	0	10,000	100	15
1100-H144	150,000	146,000	0.0	0	10,000	100	15
1100-H146	152,000	148,000	0.0	0	10,000	100	15
1100-H148	154,000	150,000	0.0	0	10,000	100	15
1100-H150	156,000	152,000	0.0	0	10,000	100	15
1100-H152	158,000	154,000	0.0	0	10,000	100	15
1100-H154	160,000	156,000	0.0	0	10,000	100	15
1100-H156	162,000	158,000	0.0	0	10,000	100	15
1100-H158	164,000	160,000	0.0	0	10,000	100	15
1100-H160	166,000	162,000	0.0	0	10,000	100	15
1100-H162	168,000	164,000	0.0	0	10,000	100	15
1100-H164	170,000	166,000	0.0	0	10,000	100	15
1100-H166	172,000	168,000	0.0	0	10,000	100	15
1100-H168	174,000	170,000	0.0	0	10,000	100	15
1100-H170	176,000	172,000	0.0	0	10,000	100	15
1100-H172	178,000	174,000	0.0	0	10,000	100	15
1100-H174	180,000	176,000	0.0	0	10,000	100	15
1100-H176	182,000	178,000	0.0	0	10,000	100	15
1100-H178	184,000	180,000	0.0	0	10,000	100	15
1100-H180	186,000	182,000	0.0	0	10,000	100	15
1100-H182	188,000	184,000	0.0	0	10,000	100	15
1100-H184	190,000	186,000	0.0	0	10,000	100	15
1100-H186	192,000	188,000	0.0	0	10,000	100	15
1100-H188	194,000	190,000	0.0	0	10,000	100	15
1100-H190	196,000	192,000	0.0	0	10,000	100	15
1100-H192	198,000	194,000	0.0	0	10,000	100	15
1100-H194	200,000	196,000	0.0	0	10,000	100	15
1100-H196	202,000	198,000	0.0	0	10,000	100	15
1100-H198	204,000	200,000	0.0	0	10,000	100	15
1100-H200	206,000	202,000	0.0	0	10,000	100	15
1100-H202	208,000	204,000	0.0	0	10,000	100	15
1100-H204	210,000	206,000	0.0	0	10,000	100	15
1100-H206	212,000	208,000	0.0	0	10,000	100	15
1100-H208	214,000	210,000	0.0	0	10,000	100	15
1100-H210	216,000	212,000	0.0	0	10,000	100	15
1100-H212	218,000	214,000	0.0	0	10,000	100	15
1100-H214	220,000	216,000	0.0	0	10,000	100	15
1100-H216	222,000	218,000	0.0	0	10,000	100	15
1100-H218	224,000	220,000	0.0	0	10,000	100	15
1100-H220	226,000	222,000	0.0	0	10,000	100	15
1100-H222	228,000	224,000	0.0	0	10,000	100	15
1100-H224	230,000	226,000	0.0	0	10,000	100	15
1100-H226	232,000	228,000	0.0	0	10,000	100	15
1100-H228	234,000	230,000	0.0	0	10,000	100	15
1100-H230	236,000	232,000	0.0	0	10,000	100	15
1100-H232	238,000	234,000	0.0	0	10,000	100	15
1100-H234	240,000	236,000	0.0	0	10,000	100	15
1100-H236	242,000	238,000	0.0	0	10,000	100	15
1100-H238	244,000	240,000	0.0	0	10,000	100	15
1100-H240	246,000	242,000	0.0	0	10,000	100	15
1100-H242	248,000	244,000	0.0	0	10,000	100	15
1100-H244	250,000	246,000	0.0	0	10,000	100	15
1100-H246	252,000	248,000	0.0	0	10,000	100	15
1100-H248	254,000	250,000	0.0	0	10,000	100	15
1100-H250	256,000	252,000	0.0	0	10,000	100	15
1100-H252	258,000	254,000	0.0	0	10,000	100	15
1100-H254	260,000	256,000	0.0	0	10,000	100	15
1100-H256	262,000	258,000	0.0	0	10,000	100	15
1100-H258	264,000	260,000	0.0	0	10,000	100	15
1100-H260	266,000	262,000	0.0	0	10,000	100	15
1100-H262	268,000	264,000	0.0	0	10,000	100	15
1100-H264	270,000	266,000	0.0	0	10,000	100	15
1100-H266	272,000	268,000	0.0	0	10,000	100	15
1100-H268	274,000	270,000	0.0	0	10,000	100	15
1100-H270	276,000	272,000	0.0	0	10,000	100	15
1100-H272	278,000	274,000	0.0	0	10,000	100	15
1100-H274	280,000	276,000	0.0	0	10,000	100	15
1100-H276	282,000	278,000	0.0	0	10,000	100	15
1100-H278	284,000	280,000	0.0	0	10,000	100	15
1100-H280	286,000	282,000	0.0	0	10,000	100	15
1100-H282	288,000	284,000	0.0	0	10,000	100	15
1100-H284	290,000	286,000	0.0	0	10,000	100	15
1100-H286	292,000	288,000	0.0	0	10,000	100	15
1100-H288	294,000	290,000	0.0				

TABLE XXI

DATA FROM KAISER ALUMINUM COMPANY  
ALUMINUM-MAGNESIUM WELDABLE ALLOYS \*

Alloy	Min. Tensile	Min. Yield	A.S.M.E. Design Stress	% Mg. Max.
5154	30,000	11,000	7,500	4.0
5086	35,000	14,000	8,750	4.5
5083	40,000	18,000	10,000	4.9
5456 **	42,000	19,000	10,500	5.5

\* Upper limit for all these alloys 150°F due to stress corrosion considerations.

\*\* Desirable to stress relieve or anneal if forming is involved.

SPECIFICATION PROPERTIES

Comparison Chart for O, H32, H34, H36 and H38 Tempers

Sheet & Plate

Alloy & Temper	Tensile Strength psi min	Yield Strength psi min	% Elongation						
			.020-.050	.051-.113	.114-.161	.162-.249	.250-.500	.501-1.000	1.001-2.000
5083-0	40,000	18,000	(to .750)				16		
5083-0	38,000	16,000	(.750-2.000)					16	16
5086-0	35,000	14,000	15	18	18	18	14	14	14
5154-0	30,000	11,000	12-14	16	18	18	18	18	18
5356-0	39,000	16,000					17	17	17
5456-0	42,000	19,000					16	16	16
5086-H32	40,000	28,000	6	8	8	8	12	12	12
5154-H32	36,000	26,000	5	8	8	8	12	12	12
5086-H34	44,000	34,000	5	6	6	6	10	10	10
5154-H34	39,000	29,000	4	6	6	7	10	10	
5086-H36	47,000	38,000	4	6	6 (to .125)				
5154-H36	42,000	32,000	3	4	5				
5154-H38	45,000	35,000	3	4	5				

TABLE XXII

**SPECIFICATION PROPERTIES**

Comparison Chart for H112, H113, and H321 Tempers

Plate

Alloy & Temper	Tensile Strength psi min	Yield Strength psi min	% Elongation			
			0.250- .500	.501- 1.000	1.001- 2.000	2.001- 3.000
5086-H112	36,000	18,000	8			
5086-H112	35,000	16,000		10		
5086-H112	35,000	14,000			14	
5086-H112	34,000	14,000				14
5154-H112	30,000	11,000	8	8	8	8
5356-H112	40,000	22,000	10			
5356-H112	38,000	20,000		12		
5356-H112	38,000	16,000			12	12
5083-H113	44,000	31,000	12	12	12	
5356-H321	42,000	26,000	12	12	12	12
5456-H321	46,000	33,000	12	12	12	

Data from Kaiser Aluminum Company.

5083 ALLOY

TABLE XXIII

Mechanical Property Limits - Plate

Temper	Thickness (inches)	Tensile Strength		Yield Strength*		Elongation in 2"
		Minimum (psi)	Maximum (psi)	Minimum (psi)	Maximum (psi)	Minimum (%)
0	0.250 - 0.750	40,000	---	18,000	---	16
	0.751 - 1.500	38,000	---	16,000	---	16
H113	0.250 - 2.000	44,000	51,000	31,000	41,000	12

\* At 0.2 percent offset.

Mechanical Property Limits - Extruded Shapes

H112	All	40,000	---	24,000	---	12
------	-----	--------	-----	--------	-----	----

Typical Mechanical Properties

Temper	Ultimate Strength (psi)	Yield Strength (psi)	Elongation in 2" (%)	Ultimate Shearing Strength (psi)	Endurance Limit (psi)	Modulus of Elasticity (psi)
0 *	42,000	22,000	21	25,000		$10.3 \times 10^6$
H113 *	46,000	33,000	16		23,000	$10.3 \times 10^6$

\* Typical values for plate only.

Physical Properties

0 Temper

Density (lbs/cu.in.)	.096 (lbs/cu.ft.)	166
Melting Range	1065 - 1180° F	
Specific Gravity	2.66	
Thermal Conductivity (CGS units)	.28; (English units)	810
Electrical conductivity (% IACS equal vol.)	29; (Equal weight)	98
Electrical resistivity (Microhms-Cm)	5.9; (Ohms-Mil.Ft.)	36

Data from Kaiser Aluminum Company

5456 ALLOY

TABLE XXIV

Mechanical Property Limits - Plate

Alloy and Temper	Thickness Inches	Tensile Strength psi		Yield Strength psi		Elongation in 2" % Min.
		Min.	Max.	Min.	Max.	
5456-0	0.250 - 2.000	42,000	53,000	19,000	30,000	16
5456-H321	0.250 - 0.624	46,000	59,000	33,000	43,000	12
	0.625 - 1.250	46,000	56,000	33,000	43,000	12
	1.251 - 2.000	44,000	56,000	31,000	43,000	12

Mechanical Property Limits - Extrusions & Rolled Structural Shapes

5456-0	Up thru 5" (32 sq.in.)	42,000	---	19,000	---	16
5456-H112	Up thru 5" (32 sq.in.)	42,000	---	19,000	---	12
5456-H311	Up thru 5" (32 sq.in.)	42,000	---	25,000	---	12

Typical Mechanical Properties

Alloy and Temper	Tensile Strength psi		Elongation % in 2" 1/16" Thick Specimen	Hardness 500 Kg Load 10 mm Ball	Shear Ultimate Shearing Strength psi	Modulus of Elasticity psi
	Ultimate	Yield				
5456-0	45,000	23,000	24	---	---	10.3 x 10 <sup>6</sup>
5456-H321	51,000	37,000	16	90	30,000	10.3 x 10 <sup>6</sup>
5456-H112	45,000	24,000	22	---	---	10.3 x 10 <sup>6</sup>
5456-H311	47,000	33,000	18	---	---	10.3 x 10 <sup>6</sup>

Typical Physical Properties

Density. . . . .	.096 lbs/cu.in.
Density. . . . .	166 lbs/cu.ft.
Specific Gravity. . . . .	2.65
Average Coefficient of Thermal Expansion . . . .	13.4
Melting Range. . . . .	1060 - 1180°F

# 5083 ALLOY SHEET AND PLATE

## Chemical Composition

	Percent		GOVERNMENT AND TECHNICAL SOCIETY SPECIFICATIONS
	Min.	Max.	
Silicon		0.40	
Iron		0.40	
Copper		0.10	MIL-A-17358 A-1
Manganese	0.30	1.00	
Magnesium	4.00	4.90	ASME Case No. 1247
Chromium		0.25	
Zinc		0.25	
Titanium		0.15	
Others, each		0.05	
Others, total		0.15	
Aluminum		Remainder	

## Mechanical Properties

Temper	Thickness in.	Tensile Strength psi-min-max	Yield Strength psi-min-max	Elongation % in 2" (min)
-O	.064-.750	40,000	18,000	16
	.751-1.500	38,000	16,000	16
-H113	.250-2.000	44,000-51,000	31,000-40,000	12

Data from Kaiser Aluminum Company.

TABLE XXVI  
 5456 ALLOY PLATE

Chemical Composition

	Percent		GOVERNMENT AND TECHNICAL SOCIETY SPECIFICATIONS
	Min.	Max.	
Magnesium	4.7	5.5	MIL-A-19842 (Ships)
Chromium	0.05	0.20	
Manganese	.90	1.00	ASME Case No. 1248
Titanium	---	.10	
Copper	.05	.20	
Zinc	---	.25	
Iron + Silicon	---	.40	
Beryllium	---	.0005	
Others, each	---	.05	
Others, total	---	.15	
Aluminum	Remainder		

Mechanical Properties

Temper	Thickness in.	Tensile Strength psi-min-max	Yield Strength * psi-min-max	Elongation % in 2" (min)
-0	0.250-2.000	42,000	19,000	16
-H321	.250-0.624	46,000-59,000	33,000-43,000	12
	.625-1.250	46,000-56,000	33,000-43,000	12
	1.251-2.000	44,000-56,000	31,000-43,000	12

\* At .02% offset

Data from Kaiser Aluminum Company.

# 5083 ALLOY EXTRUSIONS

TABLE XXVII

## Chemical Composition

	Percent		GOVERNMENT AND TECHNICAL SOCIETY SPECIFICATIONS
	Min.	Max.	
Silicon		0.40	MIL-A-19005 (SHIPS)
Iron		0.40	
Copper		0.10	
Manganese	0.3	1.0	
Magnesium	4.0	4.9	
Chromium		0.25	
Zinc		0.25	
Titanium		0.15	
Others, each		0.05	
Others, total		0.15	
Aluminum		Remainder	

## Mechanical Properties

Temper	Thickness (in.)	Tensile Strength psi-min	Yield Strength psi-min	% Elongation in 2" or 4 x diameter (min)
-H112	All	40,000	24,000	12

Data from Kaiser Aluminum Company.

## 5086 ALLOY SHEET &amp; PLATE

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DATE: 8 December 1958

TABLE XXVIII

Chemical Composition

	Percent		GOVERNMENT AND TECHNICAL SOCIETY SPECIFICATIONS
	Min.	Max.	
Silicon		0.40	
Iron		0.50	MIL-A-19070 (SHIPS)
Copper		0.10	
Manganese	0.20	0.70	ASTM B 178-55T
Magnesium	3.5	4.5	B 209-55T
Chromium		0.25	
Zinc		0.25	ASME Case No. 1222
Others, each		0.05	
Others, total		0.15	
Aluminum		Remainder	

Mechanical Properties

Temper	Thickness (in.)	Tensile Strength		Yield Strength * psi-min	% Elongation in 2" (min)
		Min.	Max.		
-0	Less than 0.051	35,000	42,000	14,000	15
	0.051-0.249, incl.	35,000	42,000	14,000	18
	0.250-2.000, incl.	35,000	42,000	14,000	14
-H32	Less than 0.051	40,000	---	28,000	6
	0.051-0.249, incl.	40,000	---	28,000	8
	0.250-2.000, incl.	40,000	---	28,000	12
-H34	Less than 0.051	44,000	---	34,000	5
	0.051-0.249, incl.	44,000	---	34,000	6
	0.250-2.000, incl.	44,000	---	34,000	10
-H36	Less than 0.051	47,000	---	38,000	4
	0.051-0.125, incl.	47,000	---	38,000	6
-H112	0.250-0.500, incl.	36,000	---	18,000	8
	0.501-1.000, incl.	35,000	---	16,000	10
	1.001-2.000, incl.	35,000	---	14,000	14
	2.001-3.000, incl.	34,000	---	14,000	14

\* At 0.2 percent offset

TABLE XXIX

WELDED PROPERTIES OF 5086 AND 5083 WITH VARIOUS  
ALUMINUM MAGNESIUM FILLER WIRES

Average Mechanical Properties of 5083-H113  
MIG Welded With Various Filler Alloys

## Transverse Tensile Data

Filler Alloy	Ultimate psi	Yield psi	Elongation, %	
			Average	Range
5254	36,500	21,300	13.5	-
5154	37,500	19,800	14.4	11-18
5356	40,100	21,300	16.5	5-20
5456	43,200	21,000	17.6	5-21
5183	43,800	21,800	15.7	13-21

Average Mechanical Properties of 5086-H112  
MIG Welded With Various Filler Alloys

## Transverse Tensile Data

Filler Alloy	Ultimate psi	Yield psi	Elongation, %	
			Average	Range
5154	35,500	14,000	15.0	9-16
5356	36,800	17,700	18.2	15-24
5183	39,100	16,600	21.5	18-24

## Aluminum-Magnesium Alloy Filler Wires

Filler Alloy	Nominal Chemical Composition, Per Cent								
	Si	FE	Cu	Mn	Mg	Cr	Zn	Ti	Others
5154	0.45	0.45	0.10	0.10	3.5	0.27	0.20	0.20	0.15
5254	0.40	total	0.05	0.01	3.5	0.27	0.20	0.05	0.15
5356	0.40	total	0.15	0.15	4.8	0.27	0.10	0.15	0.15
5183	0.40	0.40	0.10	0.75	4.8	0.25	0.25	0.15	0.15
5456	0.40	total	0.15	0.75	5.2	0.27	0.25	0.10	0.15

Data from Kaiser Aluminum Company.

TABLE XXX  
 MINIMUM BEND RADII FOR 90° COLD BENDS

<u>Temper</u>	<u>Gauge</u>	<u>Bend Factor</u>
5083:		
-0	Less than .051	1T
	.051 - .249	1-1/2T
	.250 - .499	1-1/2T
	.500 - 1.000	2T
	1.001 - 1.500	2-1/2T
-H113	.125 - .499	1-1/2T
	.500 - .750	2T
	.751 - 1.000	2-1/2T
	1.001 - 2.000	3T
5086:		
-0	Less than .051	0T
	.051 - .249	1/2T
	.250 - .499	1T
	.500 - .750	2T
-H32	Less than .051	1/2T
	.051 - .124	1T
	.125 - .249	1-1/2T
	.250 - .499	2T
-H34	Less than .051	1T
	.051 - .124	1-1/2
	.125 - .249	2T
-H36	Less than .051	1-1/2T
	.051 - .124	2T
	.125 - .249	2-1/2T
-H112	Less than .051	1T
	.051 - .249	1-1/2T
	.250 - .499	1-1/2T
	.500 - .750	2T

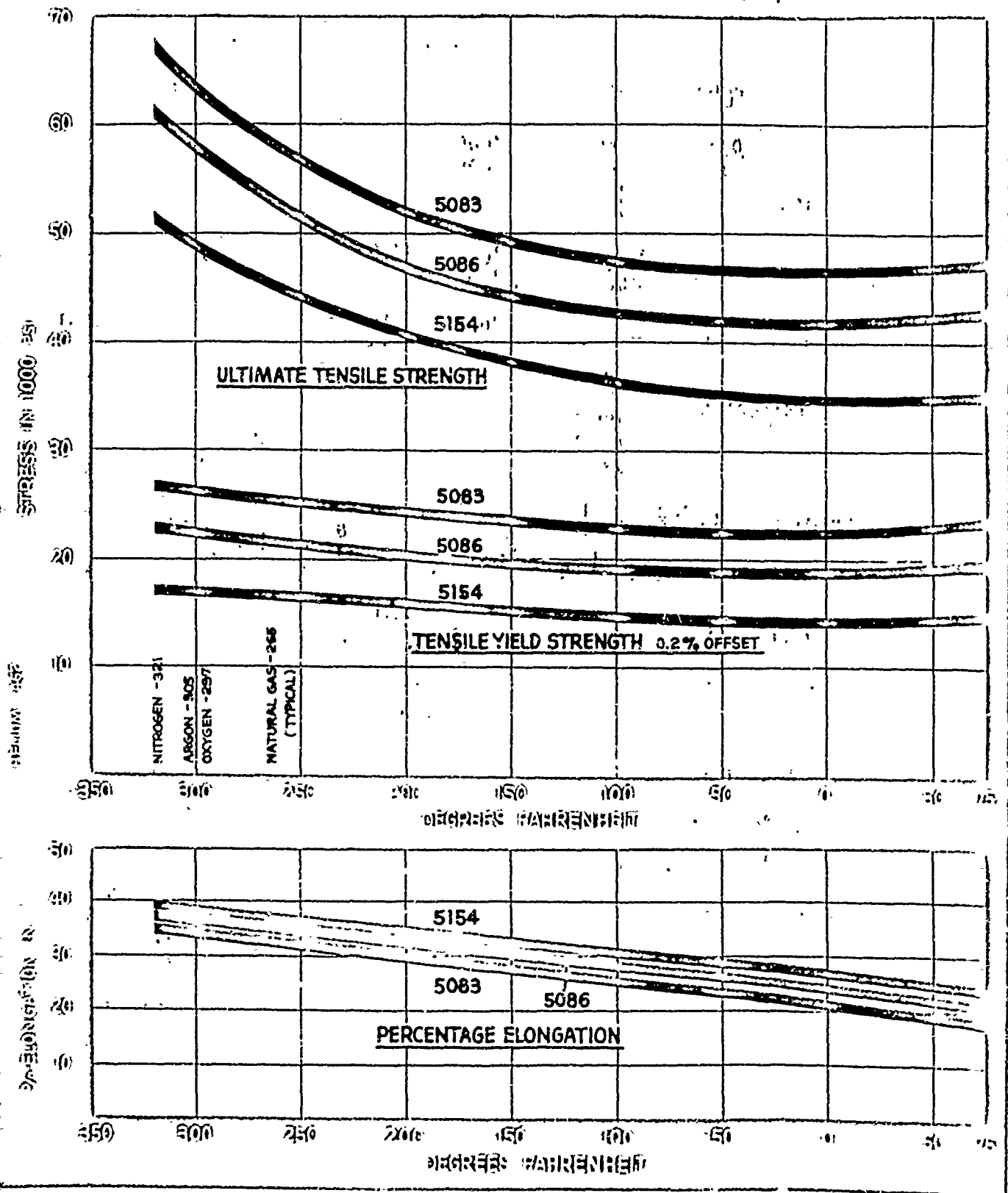
5456:

<u>Temper</u>	<u>Thickness, in.</u>	<u>Axis of Bend</u>	<u>Minimum 90° Radius, in.</u>
-0	1.250	With grain	2.500
-H321	1.250	Cross grain	3.125

Note: Hot forming at a temperature of  $450^{\circ} \pm 250^{\circ}\text{F.}$  is recommended for severe forming operations.

Data from Kaiser Aluminum Company.

TYPICAL TENSILE PROPERTIES OF ALUMINUM 5083, 5086, 5154 ALLOY TEMPERATURES



Data From Kaiser Aluminum Company.

FIG 31.

TABLE XXXI  
Mechanical Properties of 3/4-Inch 5083  
Plate and Welds as Affected by Temperature

Specimen Temper or Material	Test Temperature	Ult. Str. psi	Yield Str. psi	% Elongation in 4"
0	75F	48,500	24,100	20
	75F	48,400	24,000	21
	150F	48,300	23,900	17
	150F	48,600	23,900	16
H113	75F	50,600	37,000	18
	75F	50,900	38,100	17
	150F	52,100	36,800	15
	150F	52,100	37,400	15
0	75F	47,700	23,800	20
	75F	47,100	23,700	19
	-320F	68,100	27,200	35
	-320F	68,100	27,200	36
H113	75F	49,800	36,000	18
	75F	49,700	35,700	18
	-320F	68,300	40,700	30
	-320F	68,400	41,200	31
MIG Welds in H113 Plate Using 5183 Filler Wire	75F	45,500	22,100	20
	75F	45,800	21,900	18
	-320F	64,800	25,700	24
	-320F	64,400	25,300	23
MIG Welds in H113 Plate Using 5183 Filler Wire	75F	44,800	22,000	21
	75F	44,600	22,300	21
	-320F	61,100	24,800	21
	-320F	59,700	24,700	19

Data from Kaiser Aluminum Company.

## RESULTS OF

TEMP, °F	ALLOY	TENSILE STRENGTH, PSI	YIELD STRENGTH*, PSI	ELONG. IN 4D, %	RED. OF AREA, %	ALLOY	TENSILE STRENGTH, PSI
75	5050-0	21 500	7 000	34.3	77	5052-H38	40 100
- 18		22 500	7 600	33.8	78		40 700
-112		23 800	8 400	38.0	78		42 400
-320		37 100	9 500	45.5	70		57 900
75	5050-H34	31 000	25 500	18.2	62	5154-0	35 200
- 18		31 300	25 400	18.5	64		35 400
-112		33 600	26 300	21.5	62		36 500
-320		46 700	31 000	29.8	63		51 200
75	5050-H38	35 700	31 400	15.1	50	5154-H32	41 900
- 18		36 200	31 400	15.0	55		43 000
-112		37 900	32 200	17.5	58		44 300
-320		50 200	38 300	26.3	53		62 300
75	5052-0	29 100	14 300	33.2	72	5154-H34	43 800
- 18		29 200	14 400	35.8	74		44 000
-112		30 600	14 300	40.8	76		45 300
-320		44 800	16 800	50.0	69		55 800
75	5052-F	26 100	9 400	31.2	70	5154-H38	50 400
- 18		--	--	--	--		51 000
-112		--	--	--	--		52 200
-320		42 400	11 100	49.0	70		67 400
75	5052-H32	32 200	24 400	21.7	72	x5454-0	41 300
- 18		32 900	24 100	22.9	73		42 000
-112		34 800	24 300	26.3	74		43 000
-320		50 700	28 400	37.7	64		60 900
75	5052-H34	32 500	31 200	17.4	58	x5454-H32	42 700
- 18		36 800	30 600	18.6	62		44 100
-112		40 700	31 800	21.0	60		45 500
-320		51 400	37 100	29.7	56		63 200

\* OFFSET EQUALS 0.2 PER CENT.  
 \*\* THESE VALUES ARE CONSIDERABLY HIGHER THAN TYPICAL FOR THIS ALLOY, AND TEMPE

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# RESULTS OF TENSILE TESTS OF ALUMINUM ALLOYS AT LOW TEMPERATURES

ALLOY	TENSILE STRENGTH, PSI	YIELD STRENGTH,* PSI	ELONG. IN 4D, %	RED. OF AREA, %	ALLOY	TENSILE STRENGTH, PSI	YIELD STRENGTH,* PSI	ELONG. IN 4D, %
5052-H38	40 100 40 700 42 400 57 900	34 200 33 800 34 300 39 800	16.6 18.3 20.6 30.9	59 93 64 57	5086-0	36 500 36 400 37 100 52 400	16 000 16 600 15 600 17 000	32 32 36 19
5154-0	35 200 35 400 36 500 51 200	17 100 16 600 17 200 19 600	28.8 31.5 35.0 41.6	66 72 73 60	5086-H32	43 300 45 200 46 900 64 400	31 100 31 400 32 200 37 300	16 18 23 80
5154-H32	41 900 43 000 44 300 62 300	31 800 31 900 32 600 37 400	19.0 22.0 25.3 34.0	61 62 65 53	5083-0	45 400 46 700 47 000 62 900	21 800 21 000 21 200 23 800	23 24 27 30
5154-H34	43 800 44 000 45 300 55 800	34 600 34 600 35 400 39 800	17.0 19.8 20.5 23.0	55 52 64 58	5083-H113	49 800 51 000 52 100 67 800	40 800 38 700 42 200 48 400	15 18 19 25
5154-H38	50 400 51 000 52 200 67 400	42 100 42 300 43 800 49 900	14.2 16.8 19.8 24.4	45 55 56 48	5356-0	42 100 42 800 43 300 61 300	19 200 19 400 19 700 22 200	30 33 33 41
x5454-0	41 300 42 000 43 000 60 900	23 300 23 000 23 200 27 600	19.0 22.5 26.0 33.5	22 47 51 40	5356-H32	46 300 46 600 47 500 63 900	32 000 32 100 32 600 37 100	2 2 2 3
x5454-H32	42 700 44 100 45 500 63 200	28 000 29 300 30 300 35 100	16.0 19.0 22.5 31.0	30 33 44 35	5356-H34	53 200 53 900 55 100 73 400	40 100 40 400 41 200 47 100	1 1 2 2

FOR THIS ALLOY, AND TEMPER.

B

TEMPERATURES

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TENSILE STRENGTH, PSI	YIELD STRENGTH,* PSI	ELONG. IN 4D, %	RED. OF AREA, %	ALLOY	TENSILE STRENGTH, PSI	YIELD STRENGTH,* PSI	ELONG. IN 4D, %	RED. OF AREA, %
36 600	16 000	32.0	55	5056-0	44 900	24 700	31.2	57
35 400	16 600	32.0	60		44 100	23 200	34.9	65
37 100	15 600	36.0	62		43 900	23 300	36.6	67
52 400	17 000	49.0	52		61 200	26 900	46.9	56
43 300	31 100	16.0	27	5056-H32	49 000	33 300	23.0	57
45 200	31 400	18.0	38		48 000	33 400	24.0	63
46 900	32 200	23.0	45		48 900	33 900	27.0	67
64 400	37 300	30.0	35		66 000	38 300	36.0	53
45 400	21 800	23.0	35	5056-H34	55 300	40 600	18.0	47
46 700	21 000	24.5	39		54 200	40 400	20.0	58
47 000	21 200	27.0	47		55 200	41 200	22.5	61
62 900	23 800	33.0	38		73 300	46 200	29.5	40
49 800	40 800	15.5	29	5056-H38	57 000	42 400	17.8	44
51 000	38 700	18.0	37		57 400	43 400	18.7	46
52 100	42 200	19.0	40		58 100	44 500	21.3	56
67 800	48 400	25.0	36		75 900	50 200	28.0	44
42 100	19 200	30.0	54	5456-0	50 800	24 100	20.0	26
42 800	19 400	31.5	65		49 900	23 700	22.5	34
43 300	19 700	33.5	66		46 700	24 000	25.5	41
61 300	22 200	42.5	48		66 000	26 800	30.0	33
46 300	32 000	24.0	54	5456-H321	55 000	38 200	12.0	16
46 600	32 100	24.0	62		57 600	39 600	13.5	19
47 500	32 600	27.0	64		57 500	39 200	17.0	27
63 900	37 100	34.0	53		74 100	45 400	22.5	21
53 200	40 100	16.5	51					
53 900	40 400	18.5	55					
55 100	41 200	21.0	58					
73 400	47 100	27.5	43					

MECHANICAL TESTING DIVISION  
ALCOA RESEARCH LABORATORIES  
NEW KENSINGTON, PA.

FEBRUARY 10, 1953

C

DATA FROM WADC REPORT NO. TR58-386

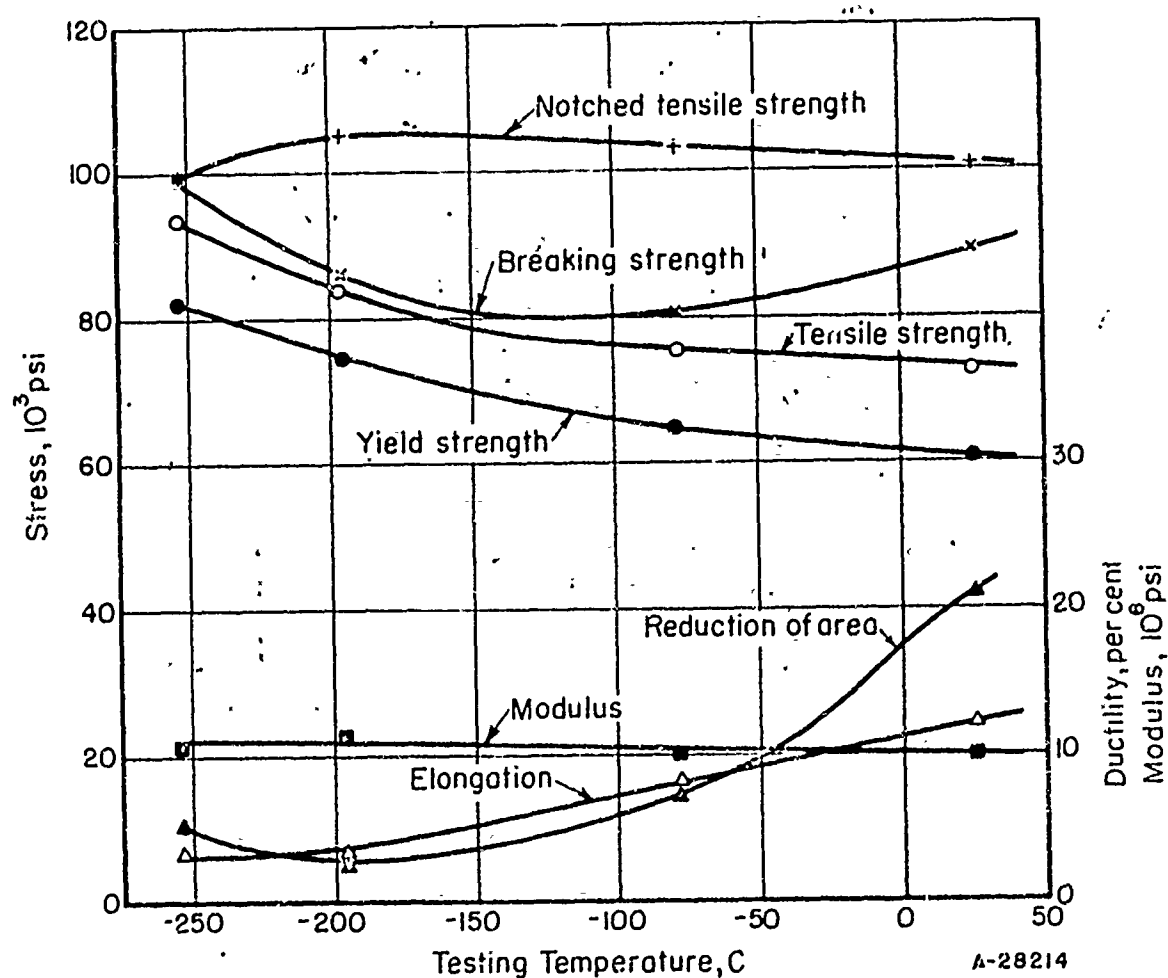


FIGURE 32 MECHANICAL PROPERTIES OF 7079-T6 ALUMINUM-ALLOY BILLET

TABLE XXXIII

TENSILE PROPERTIES OF AIRCRAFT ALLOYS

AT -253°C (LH<sub>2</sub>) -423°F

	24S-T4	75S-T4	Titanium	NE 8630	18-8 Stainless Steel (Type 304)
<b>POLISHED SPECIMENS</b>					
Ultimate Tensile Strength (psi)	105,600	109,600	245,600	182,500	322,800
Breaking Strength (psi)	105,600	109,600	245,600	182,500	
True Breaking Strength (psi)	118,600	118,300	257,700	182,500	
Yield Strength (psi)	76,400	96,100	215,500	182,500	303,500
Reduction of Area (%)	11.0	7.1	4.7	None <sup>1</sup>	18.1
Elongation (%)	15.4	4.5	1.3	None <sup>1</sup>	3.92
<b>NOTCHED SPECIMENS <math>K_t = 2.5</math></b>					
Ultimate Tensile Strength (psi)	104,300	113,400	130,300		
Breaking Strength (psi)	104,300	113,400	130,300		
True Breaking Strength (psi)	104,300	113,400	130,300		
Yield Strength (psi)	104,300	113,400	130,300		
Reduction of Area (%)	None <sup>1</sup>	None <sup>1</sup>	None <sup>1</sup>		
Elongation % in 1/4 inch <sup>2</sup>	0.98	0.83	None <sup>1</sup>		
	0.19	0.11	None <sup>1</sup>		

1. None means that the plastic deformation was so small as to be immeasurable.
2. The 1/4 inch gage length extends 1/8 inch away from the root of the notch on each side.
3. See Results and Discussion for explanation of this behavior.

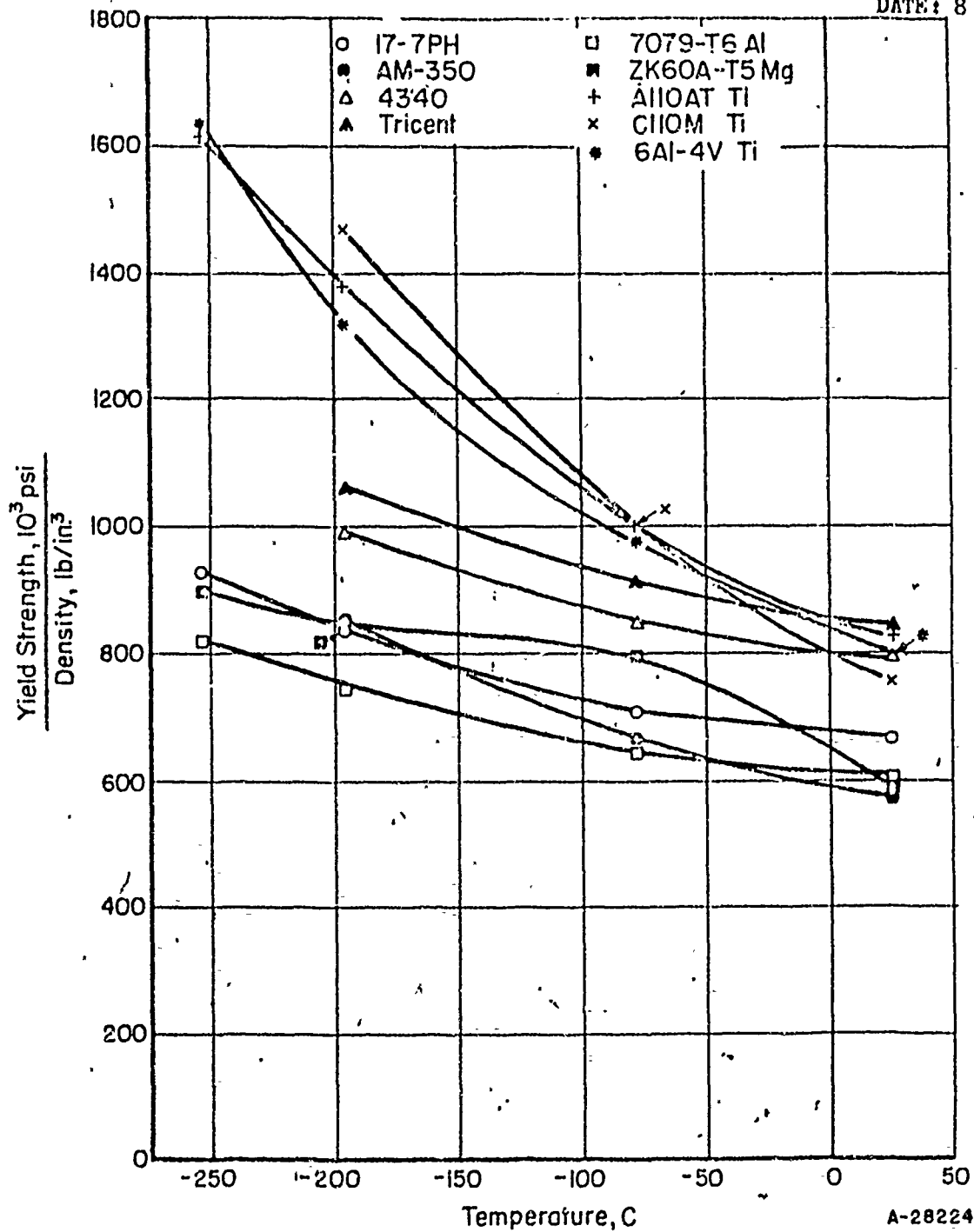


FIGURE 33. YIELD STRENGTH-DENSITY RATIOS FOR THE NINE MATERIALS FROM ROOM TEMPERATURE TO -253 C  
 Data from WADC Report 58-386.

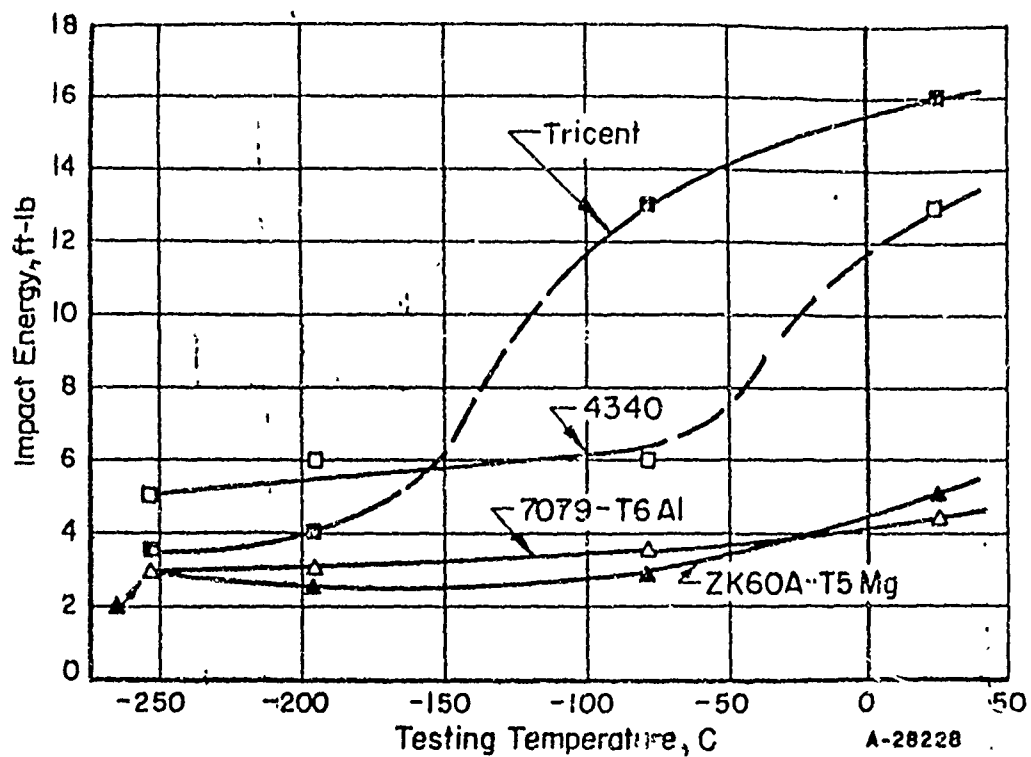


FIGURE 34. IMPACT ENERGY OF STANDARD V-NOTCH CHARPY SPECIMENS AT ROOM TEMPERATURE AND LOW TEMPERATURES

DATA FROM WADC REPORT 58-386

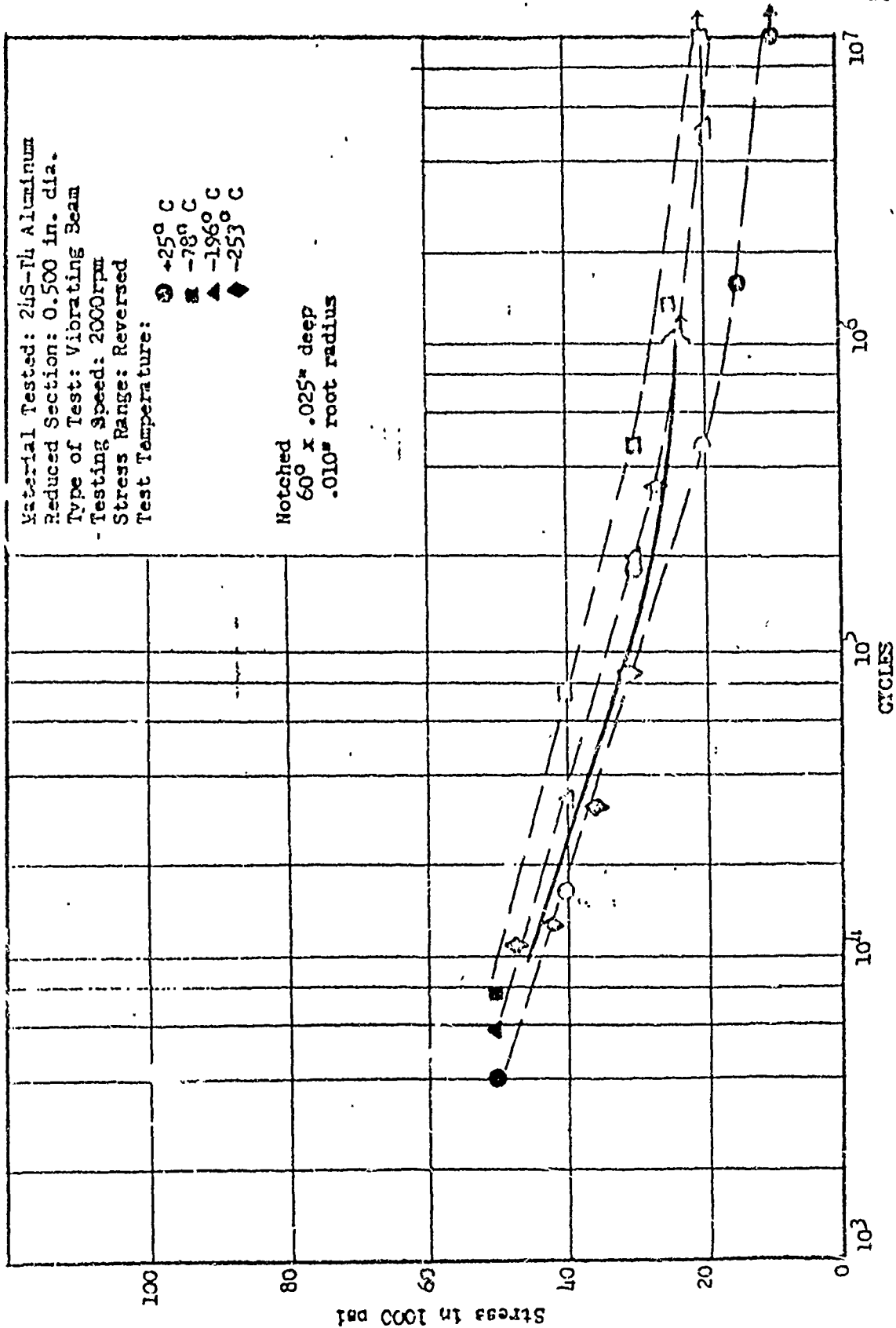


Figure 35. Results of Vibrating Beam Tests of Notched 24S-T4 Aluminum Specimens.

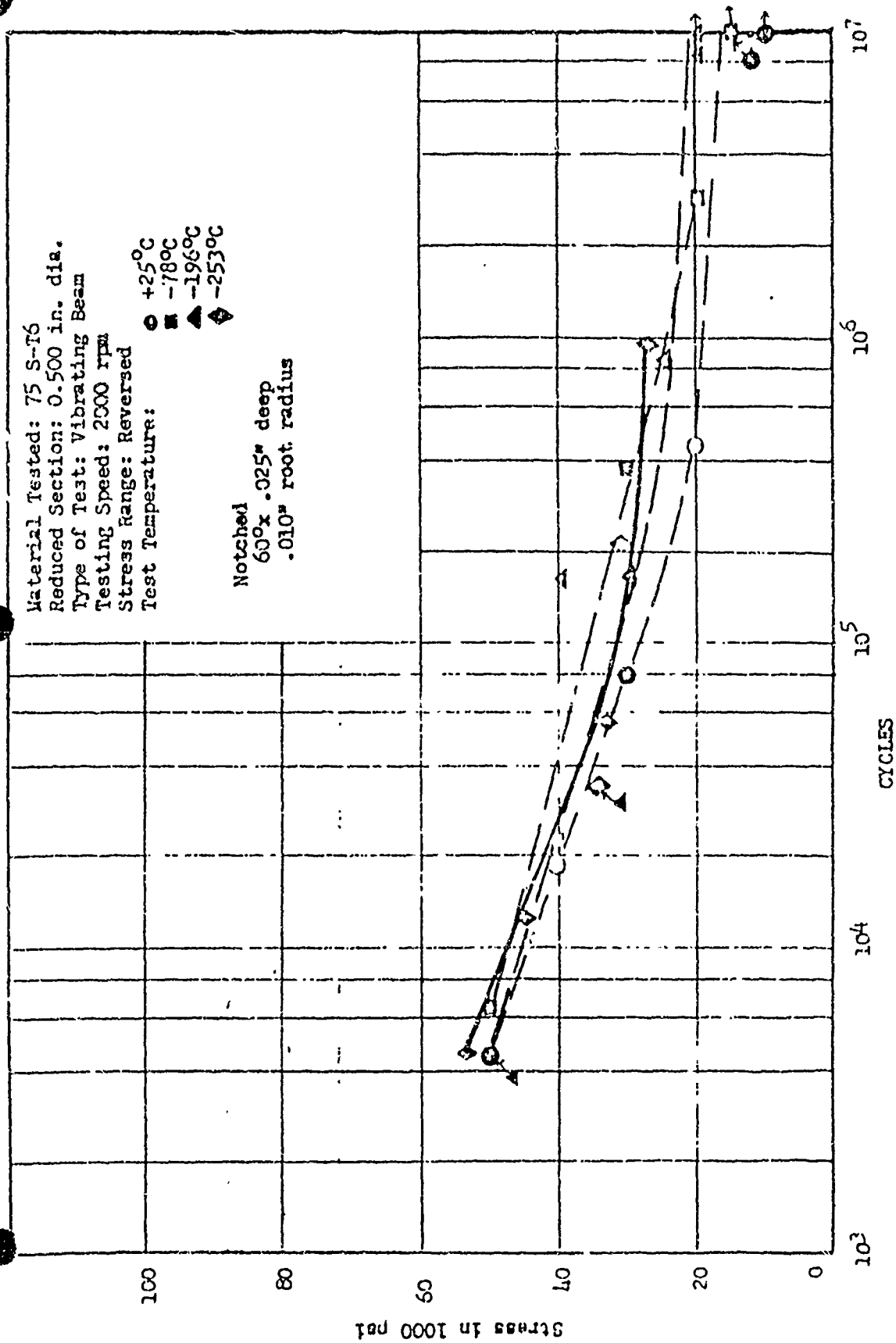


Figure 36 Results of Vibrating Beam Tests of Notched 75S-T6 Aluminum Alloy Specimen.  
 DATA FROM WADC REPORT 5662, PART 5

TABLE XXXIV

RESULTS OF NOTCHED FATIGUE TESTS OF AIRCRAFT ALLOYS  
AT -253°C

Material	Run 1		Run 2		Run 3		Run 4	
	Stress (psi)	Cycles	Stress (psi)	Cycles	Stress (psi)	Cycles	Stress (psi)	Cycles
24S-T4	42,300	13,200	36,200	30,000	29,100	83,000	26,400	1,000,000*
75S-T6	27,500	965,200	53,600	4,600	34,800	34,500	31,300	215,600
NE 8630			84,100	1,100	75,100	2,300	64,700	11,500
Titanium	68,300	10,500	64,800	16,500	47,600	63,100	51,200	71,200
18-8 Stainless Type 304	44,300	318,000	51,900	1,100,000*	61,100	35,200	57,800	46,600
Material	Run 5		Run 6		Run 7		Run 8	
	Stress (psi)	Cycles	Stress (psi)	Cycles	Stress (psi)	Cycles	Stress (psi)	Cycles
24S-T4	47,300	11,800	28,300	347,800				
75S-T6	32,900	56,000	44,800	13,200				
NE 8630	62,400	22,600	71,000	42,800				
Titanium	41,000	151,800	44,500	176,800	36,700	1,000,000*		
18-8 Stainless Type 304	56,700	64,200	56,200	1,000,000*	69,000	35,000	80,200	14,700

\* No failure

Data from WADC Report 5662, Part 5

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MEMORANDUM ON MECHANICAL PROPERTIES OF TITANIUM AND OTHER MATERIALS AT LOW TEMPERATURES  
TITANIUM METALLURGICAL LABORATORY, BATTELLE  
MEMORIAL INSTITUTE --- April 25, 1957

Material	Temp. of	0.02%		Ultimate Strength psi	Reduction in Area %	Elong. %	Impact Strength Ft. Lbs.	Hardness VHN	Modulus of Elasticity 10 <sup>5</sup> psi
		Yield Strength psi							
Unalloyed Ti (Ti-75%)	RT	70,000		84,000	48	25	-		
	-100	80,000		100,000	25	15	22		
	-321	132,000		148,000	25	25	11		
Comm. Pure Ti	RT			79,000	50	22	18		
	-106			100,000	50	19	14		
	-238			117,000	58	27	6		
	-320			114,000	54	41	10		
Comm. Pure Ti w/0.025% Notch	RT			94,000	17	-	-		
	-106			113,000	11	-	-		
	-320			149,000	9	-	-		
Comm. Pure Ti w/0.125% Notch	RT			137,000	21	-	-		
	-106			167,000	17	-	-		
	-320			231,000	10	-	-		
Comm. Pure Ti Wire, 0.040" Dia.	RT	79,800		83,400	-	10.4	-		
	-106	100,500		107,000	-	10.6	-		
	-320			150,800	-	-	-		
Comm. Pure Ti Wire, 0.040" Dia. Irradiated	RT	88,700		92,200	-	8.3	-		
	-106	108,500		112,100	-	4.8	-		
	-320			165,400	-	-	-		
Iodide Ti	RT			39,500	88	-	-		
	-106			58,500	92	-	-		
	-320			95,000	74	-	-		
Iodide Ti +0.1% Oxygen	RT			62,000	60	-	-		
	-106			94,000	37	-	-		
	-320			127,000	33	-	-		

TABLE XXV  
MEMORANDUM ON MECHANICAL PROPERTIES OF TITANIUM AND OTHER MATERIALS AT LOW TEMPERATURE  
TITANIUM METALLURGICAL LABORATORY, BATTELLE  
MEMORIAL INSTITUTE --- April 25, 1957

Material	Temp. °F	0.02% Yield Strength psi	Ultimate Strength psi	Reduc- tion in Area %	Elong. %	Impact Strength Ft. Lbs.	Hardness VHN	Modulus of Elasticity 10 <sup>6</sup> psi
Iodide Ti +0.2% Oxygen	RT -106 -320		79,500 116,500 145,000	41 55 14				
Iodide Ti +0.3% Oxygen	RT -106 -320		91,500 112,500 163,500	22 14 6	-			
Iodide Ti +0.1% Nitrogen	RT -106 -320		75,000 96,000 134,500	39 35 26				
Iodide Ti +0.15% Nitrogen	RT -106 -320		93,500 122,500 156,500	46 16 9				
Iodide Ti +0.1% Carbon	RT -106 -320		45,000 76,500 123,500	58 44 45				
Iodide Ti +0.2% Carbon	RT -106 -320		48,000 76,500 147,500	62 60 20				
A55 A55 Notched A55 Vacuum Annealed (18ppmH)	-321 -321 RT -40 -320	58,500	156,000 208,000 70,500	50 56	29.5 33	30 34 39	186	
A55 (390ppmH)	RT -40 -320	57,000	71,500	52	37	3	199	
A-70 A-70 Notched	-321 -321		155,000 199,000	35.5	24.5	2		

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TABLE IV  
MEMORANDUM ON MECHANICAL PROPERTIES OF TITANIUM AND OTHER MATERIALS AT LOW TEMPERATURES  
TITANIUM METALLURGICAL LABORATORY, BATTELLE  
MEMORIAL INSTITUTE --- April 25, 1957

Material	Temp. °F	0.02% Yield Strength psi		Ultimate Strength psi	Rduc- tion in Area %	Elong. %	Impact Strength Ft. Lbs.	Hardness VHN	Modulus of Elasticity 10 <sup>6</sup> psi
A-110 AT Sheet	RT	135,000		138,800		16.8% in 2"			
	-106	162,800		170,300		9.9% in 2"		15.6	
	-320	225,300		230,000		4.9% in 2"		16.2	
A-110 AT Sheet Notched-60° U, 0.040 radius, 0.500 hook on 1,000 wide specimen	RT	183,500		183,500		0.043"/2"			
	-106	214,000		214,000		0.034		17.1	
	-320	276,000		276,000		0.019			
A-110AT (Ti- 5Al-2.5Sn	RT	123,000		133,000	40	16			
	-100	143,000		100,000	26	14	17		
	-321	150,000		231,000	24.5	11.5			
A-110AT	-321			222,000					
5Al-2.5Sn (welded)	RT								
	-40								
	-320								
RC-130B (Polished)	RT	143,000		149,000	41.3	19.6	10.0	358	16.8
	-106	169,000		172,000	25.5	15.0	5.7	442	17.3
	-197						5.3	481	
	-320	254,000		256,000	4.9	2.1	2.6	602	18.9
	-423						3.3	742	
RC-130B (Ti-4Al-4Mn	RT	144,000		150,000	42	16	10		
	-110	166,000		182,000	35	12	5.7		
	-321			247,000	20	7	2.6		
	-423						3.3		
RC-130B with 0.025 Notch	RT	183,000		188,000	3.2	3.7% in 1"			
	-106	200,000		200,000		0.5% in 1"			
	-320	177,000		177,000		1.1% in 1"			
RC-130A	-100			160,000	11	13	10		
	-200			175,000	10	12			
	-321			220,000	4	6			

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TABLE XXV  
MEMORANDUM ON MECHANICAL PROPERTIES OF TITANIUM AND OTHER MATERIALS AT LOW TEMPERATURE  
(Continued)

Material	Temp- of	0.02% Yield Strength psi	Ultimate Strength psi	Reduc- tion in Area %	Elong. %	Impact Strength Ft.lbs.	Hardness VHN	Modulus of Elasticity $10^6$ psi
Ti-8Mn Vacuum Annealed (19ppm H)	RT -40 -320	125,500	133,500	60	35	12 6 Notched 4	304	
Ti-8Mn (368ppm H)	RT -40 -320		137,000	13	13	12 6 Notched 4	302	
C-110M Sheet	RT -106 -320	127,000 169,000 247,000	140,000 176,500 260,000		14.8% in 2" 13.3 5.2			15.5 16.6 17.3
C-110M Sheet Notched 60° U, 0.040 Radius, -106 0.500 root on 1000 wide specimen	RT -320		151,000 191,000 254,800		0.047% / 2" 0.04 0.005			
C-120AV (6Al-4V)	-321		236,000	27	10.2	20		
C-120AV (Notched)	-321		289,000			25		
Ti-6Al-4V	RT -40 -110 -320	156,000	172,000	27.4	9.5	23 20		
Ti-6Al-4V	RT -40 -360		238,000 166,000		9.4 8.0	12 12.5 10.7		
6Al-4V 1/2" Plate Mill Annealed Long. Grain	RT -320	146,000	230,000	33.0 35.4	7.5	9.5 18.5 13.5		
6Al-4V 1/2" Plate Water Quenched Long. Grain (1900F 1/2 HR)	RT -320					14 11		
6Al-4V 1/2" Plate Mill Annealed Trans. Grain	RT -320					19 15		
6Al-4V 1" Round Mill Annealed	RT -320					17 16		
6Al-4V 1/2" Plate Water Quenched Trans. Grain (1900F 1/2 HR)	RT -320					14.5 14.5		

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SYNOPSIS OF MECHANICAL PROPERTIES OF TITANIUM AND OTHER MATERIALS AT LOW TEMPERATURE

(Continued)

Material	Temp. of Test	0.02% Yield Strength psi	Ultimate Strength psi	Reduction in Area %	Elong. %	Impact Strength ft. lbs.	Hardness VHN	Modulus of Elasticity $10^6$ psi
6Al-4V 0.2% Round Mill Annealed. .)	RT -320					17 16		
6Al-4V 3-3/16" x 2- 15/16" Mill Anneal- ed	RT -320					15 15		
6Al-4V 1/2" Plate as Welded	RT -320					24 12		

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TABLE XXXVI  
MECHANICAL PROPERTIES OF 6Al-4V-TITANIUM ALLOY

As Received Material, Mill Annealed:  
(average of two tests)

Direction of Test	Yield Strength psi	Tensile Strength psi	% Elong.	% R. A.	V-Notch Charpy +70°F	V-Notch Charpy -320°F
Long.	128,500	137,500	17.8	44	18.8	13.0
Trans.	127,750	139,500	15.7	43.5	12.8	9.0

Heat Treated:  
(1725°F, 1 hr., WQ-1050°F, 2 hrs., air cool)  
(average of 2 tests)

Long.	145,750	162,500	20.0	54.4	16.8	12.3
Trans.	151,500	165,250	17.1	56.7	12.4	8.5

Heat Treated Material:

Test Temp.					V-Notch Charpy Impact Ft.Lbs.*
+70°	137,000	156,100	16.2	52.6	17.7
+70°	138,100	153,300	16.2	45.1	15.0
-320°	228,700	236,400	11.1	36.4	10.0
-320°	237,800	244,100	11.8	27.5	9.0

\* Double width (0.788"), half thickness (0.197"), with standard V-notch, but  $\frac{1}{2}$  depth of notch.

TABLE XXXVII  
MECHANICAL PROPERTIES OF RS-140 TITANIUM  
ALLOY

Longitudinal tests from 1/4" thick plate, Heat R-11730; samples mill annealed at 1425°F, 1 hour in furnace - air cooled. Chemistry - .031C, .010N<sub>2</sub>, 4.90Al, 1.05Fe, 2.7Cr.

Test Temp.	Yield Strength 0.2% Offset psi	Tensile Strength psi (1)	% Elong.	% R. A.	V-Notch Charpy Impact Ft. Lbs. (2)
+70°	147,700	156,600	15.5	45.1	30
+70°	147,100	158,300	17.7	43.3	25
+70°	147,600	158,800	17.7	49.4	
+70°	147,100	157,400	13.3	41.6	
+70°	<u>147,000</u>	<u>158,300</u>	<u>15.5</u>	<u>38.6</u>	—
Average	147,300	157,900	15.9	43.6	27.5
-320°F	236,500	244,000	11.1	19.5	6.8
-320°F	<u>233,000</u>	<u>244,200</u>	<u>15.1</u>	<u>18.1</u>	<u>8.5</u>
Average	234,700	244,100	13.1	18.8	7.7

NOTES:

- (1) Tensile test specimens were 0.113" diameter round shank, with 0.45" gage length.
- (2) V-notch Charpy specimens were twice standard width (0.788"), 1/2 standard thickness (0.197") and 1/2 standard notch depth (0.039"), but with standard notch contour.

TABLE XXXVIII

ADDITIONAL DATA ON MILL ANNEALED RS-140 TITANIUM ALLOY

<u>Test Temperature</u>	<u>Yield Strength 0.2% Offset</u>	<u>Tensile Strength psi</u>	<u>% Elong.</u>	<u>% R. A.</u>
Room Temperature	151,200	160,200	13.3	44
Room Temperature	146,700	156,700	17.7	37.7
Room Temperature	150,200	160,600	15.5	47.5
-320°	232,300	243,700	13.3	25.3
-320°	232,000	242,200	13.3	23.7
-320°	233,800	243,900	13.3	37.4
-320°	232,600	244,000	13.3	36.0
-320°	231,700	241,700	13.3	32.3

TABLE XXXIX

MECHANICAL PROPERTIES OF B120 VCA TITANIUM ALLOY

<u>As Received</u>	<u>Test Temperature</u>	<u>T. S. (1) psi</u>	<u>Y. S. 0.2% Offset, psi</u>	<u>% Elong.</u>	<u>% R. A.</u>	<u>V-Notch Charpy Impact (2) Ft. Lbs.</u>
<u>Direction</u>						
Trans.	+70	150,400	140,600	18.8	54.0	6.0
Trans.	+70	148,200	140,400	17.2	53.0	-
Long.	+70	144,300	136,300	21.9	55.0	-
Long.	+70	145,800	137,700	18.8	54.0	-
Trans.	-320	251,700		1.5	1.5	1.4
Trans.	-320	239,800		1.5	0	1.5
Long.	-320	148,400		1.5	0.5	-
Long.	-320	197,000		1.5	1.0	-
<u>Annealed at Convair-Astronautics. Heated to 1400°F, held 30 minutes, air cooled.</u>						
Trans.	+70	144,100	139,200	21.9	54.0	10.0
Trans.	+70	144,900	137,600	17.2	52.0	9.9
Long.	+70	140,900	133,500	23.4	59.0	-
Long.	+70	141,500	134,200	21.9	56.0	-
Trans.	-320	214,900		1.5	0.5	1.3
Trans.	-320	246,300		4.6	1.5	1.5
Long.	-320	234,800		1.5	1.0	-
Long.	-320	265,800		1.5	0	-

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NOTES:

- (1) Tensile test specimens were 0.160" diameter round shank, with 0.64" gage length.
- (2) V-Notch Charpy specimens were twice standard width (0.788"), 1/4 standard thickness (0.197"), and 1/4 standard notch depth (0.039"), but with standard notch contour.

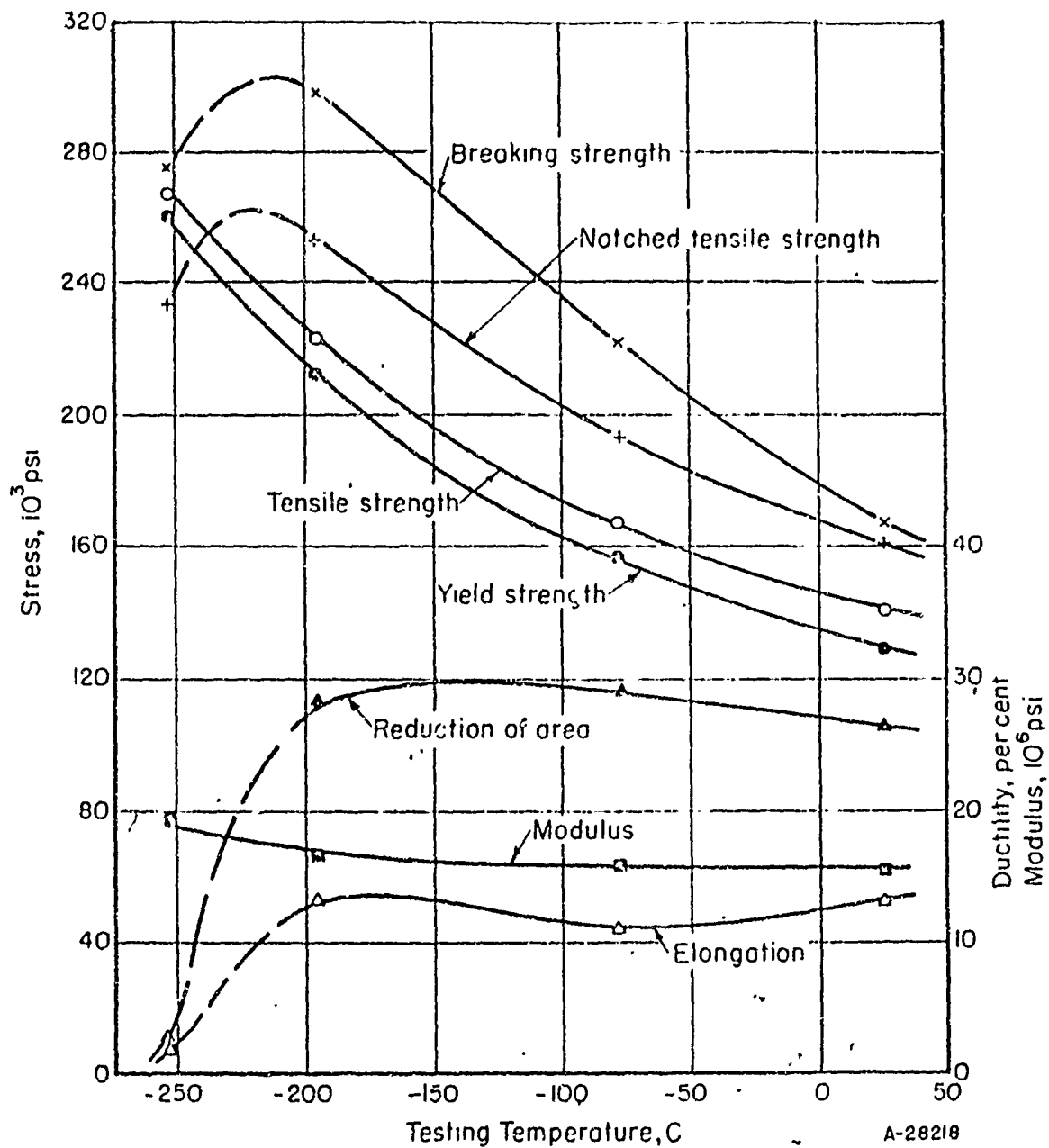


FIGURE 37. MECHANICAL PROPERTIES OF 6Al-4V  
 TITANIUM-ALLOY SHEET  
 DATA FROM WADC REPORT 58-386

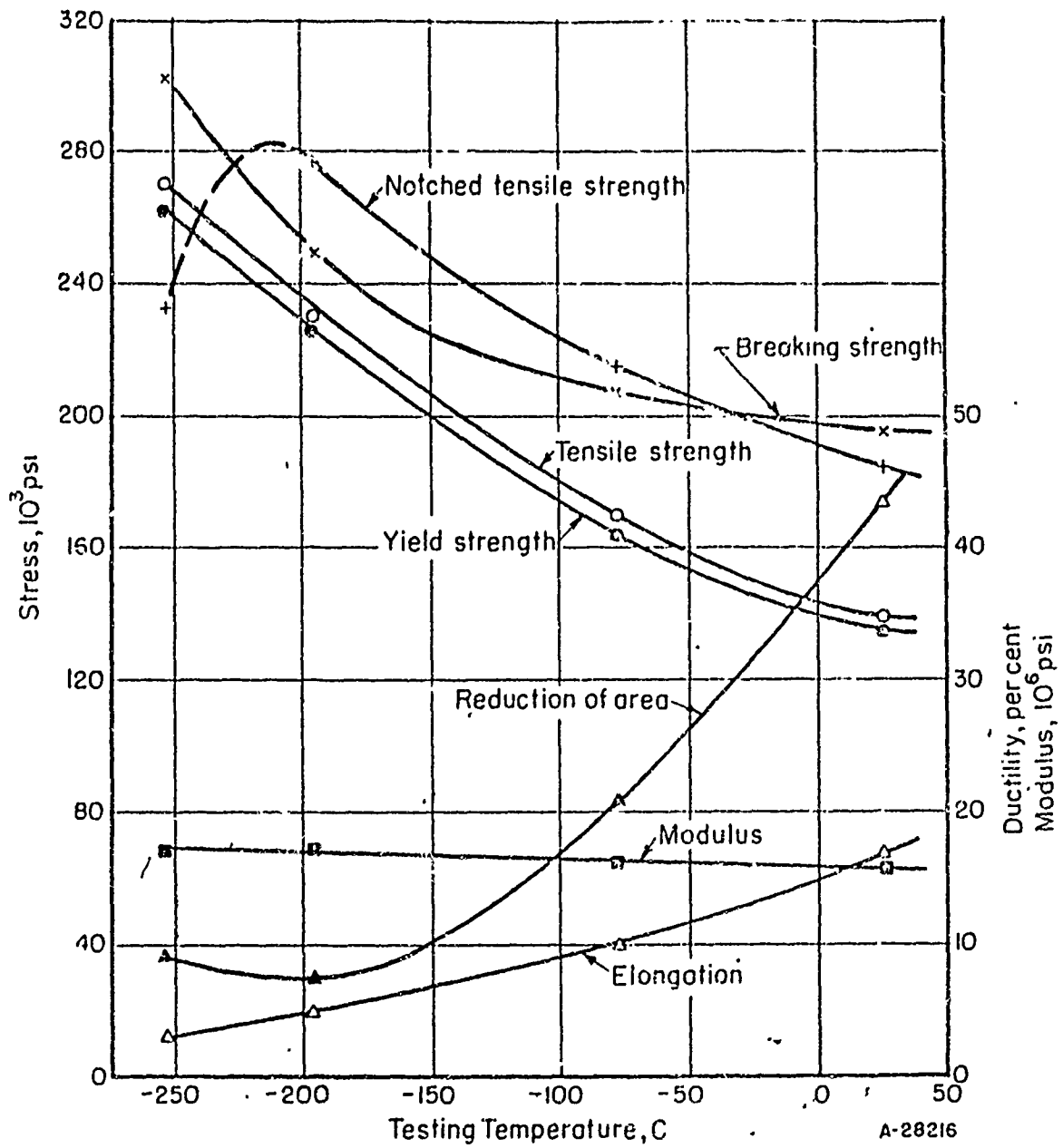


FIGURE 38. MECHANICAL PROPERTIES OF A110AT  
 TITANIUM-ALLOY SHEET  
 DATA FROM WADC REPORT 58-386

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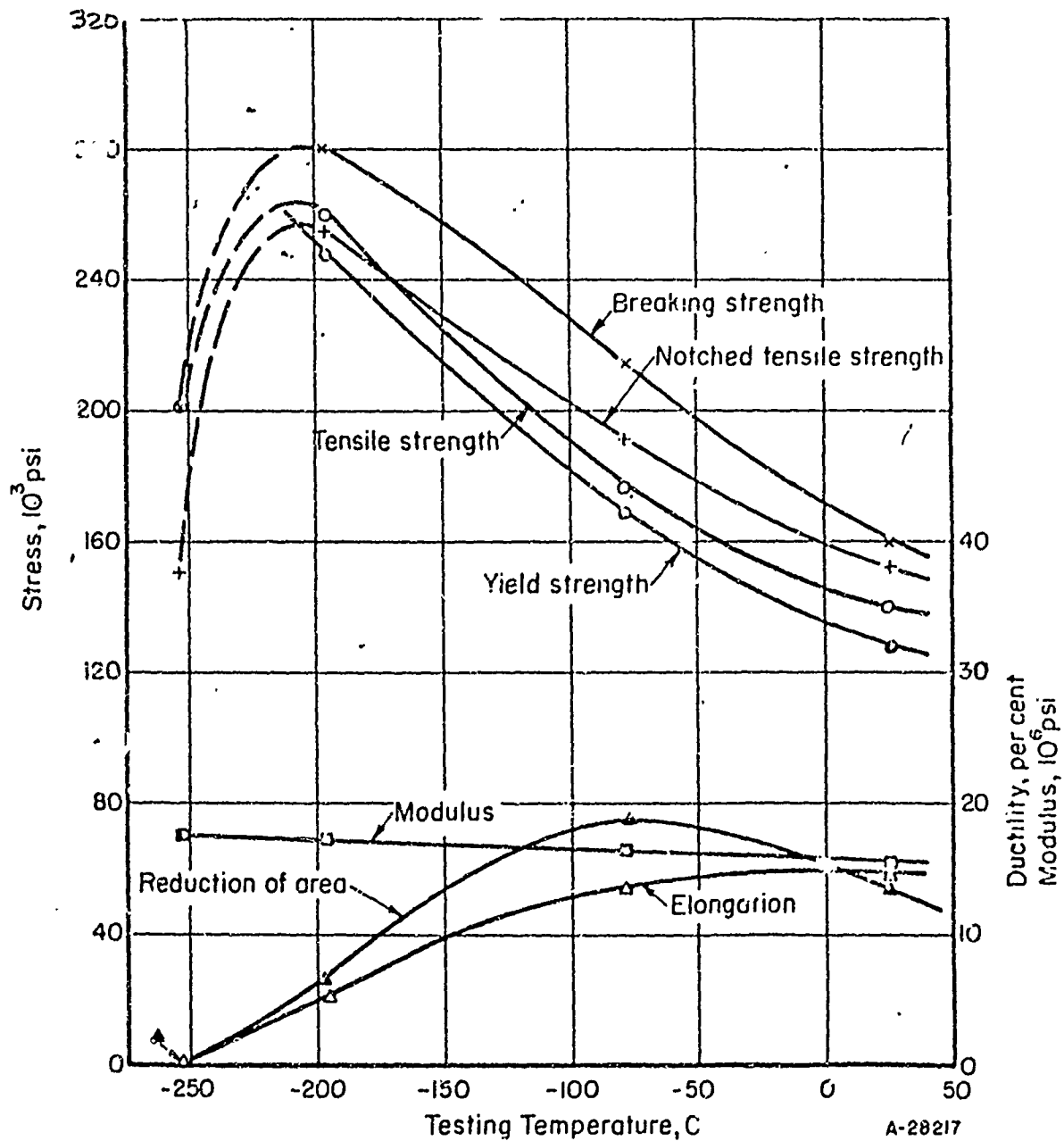


FIGURE 39. MECHANICAL PROPERTIES OF C110M  
 TITANIUM-ALLOY SHEET

DATA FROM WADC REPORT 56-386

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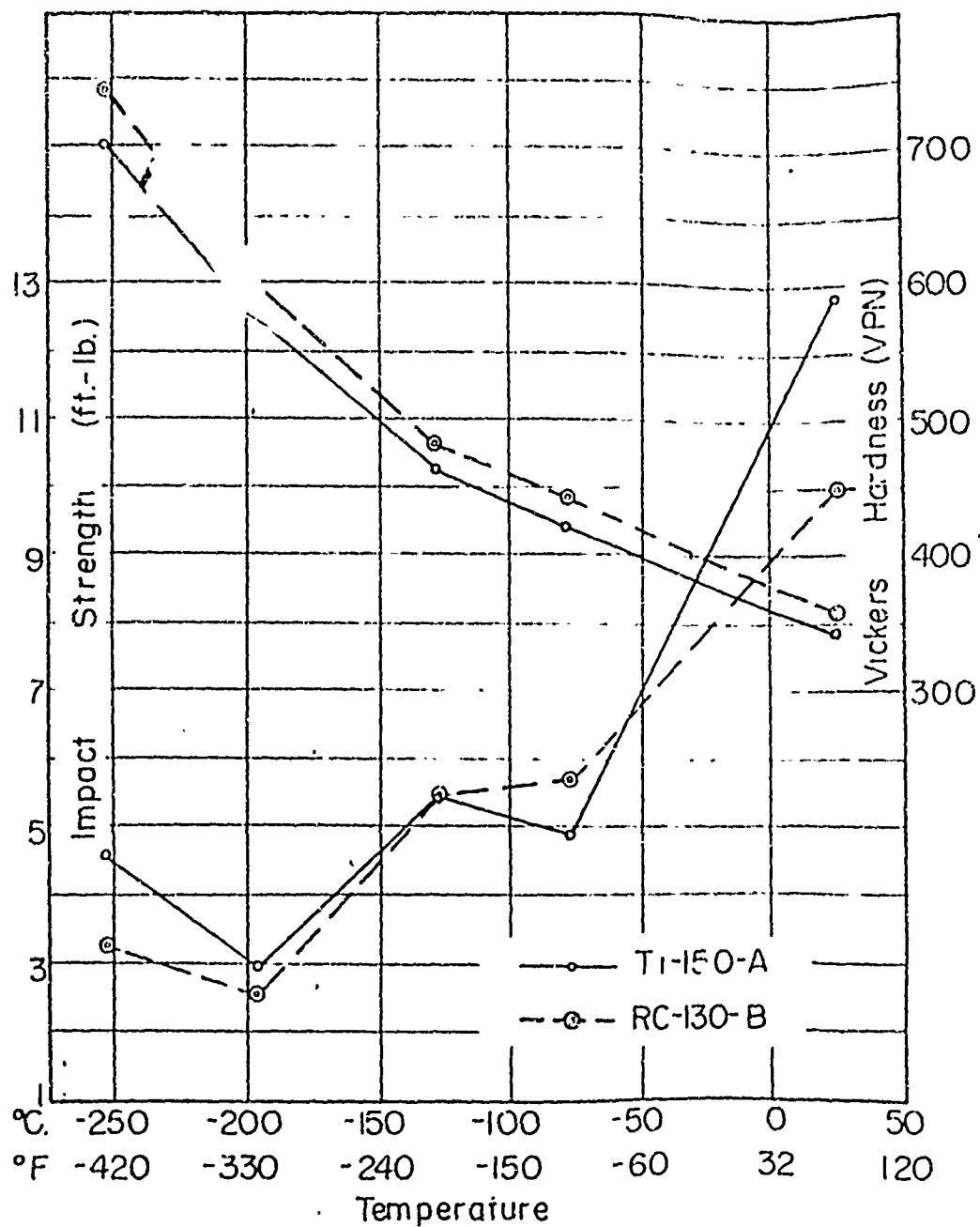


Figure 10 Impact strength and hardness of Ti-150-A & RC-130-B  
 DATA FROM WADC REPORT 5662, PART 5

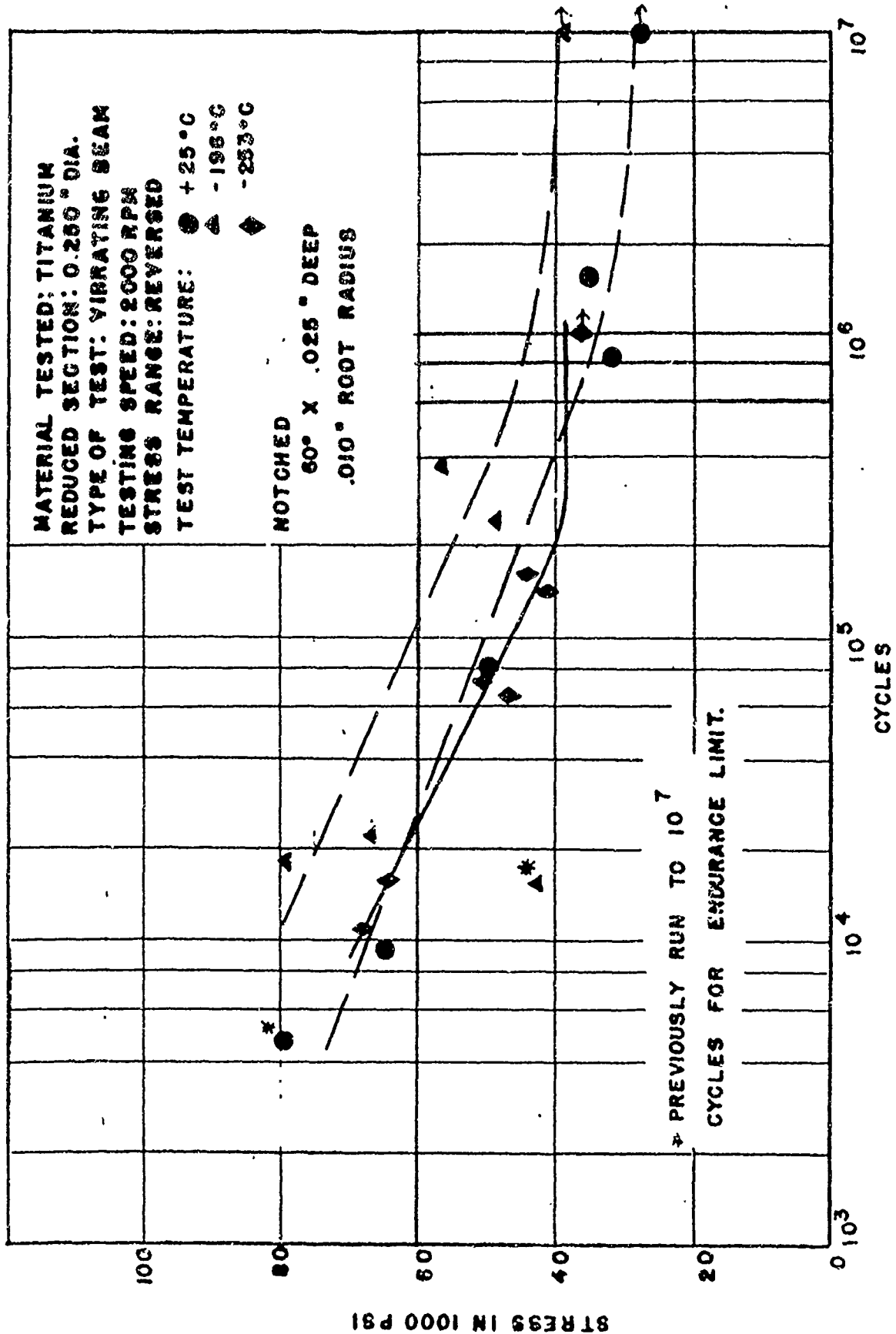


FIGURE 41. RESULTS OF VIBRATING BEAM TESTS OF NOTCHED TITANIUM SPECIMENS  
 AT -253°C (423°F). CURVES FOR +25°C AND -196°C FOR COMPARISON.  
 DATA FROM NATA REPORT 5662, PART 5

DATA FROM CASE INSTITUTE OF TECHNOLOGY

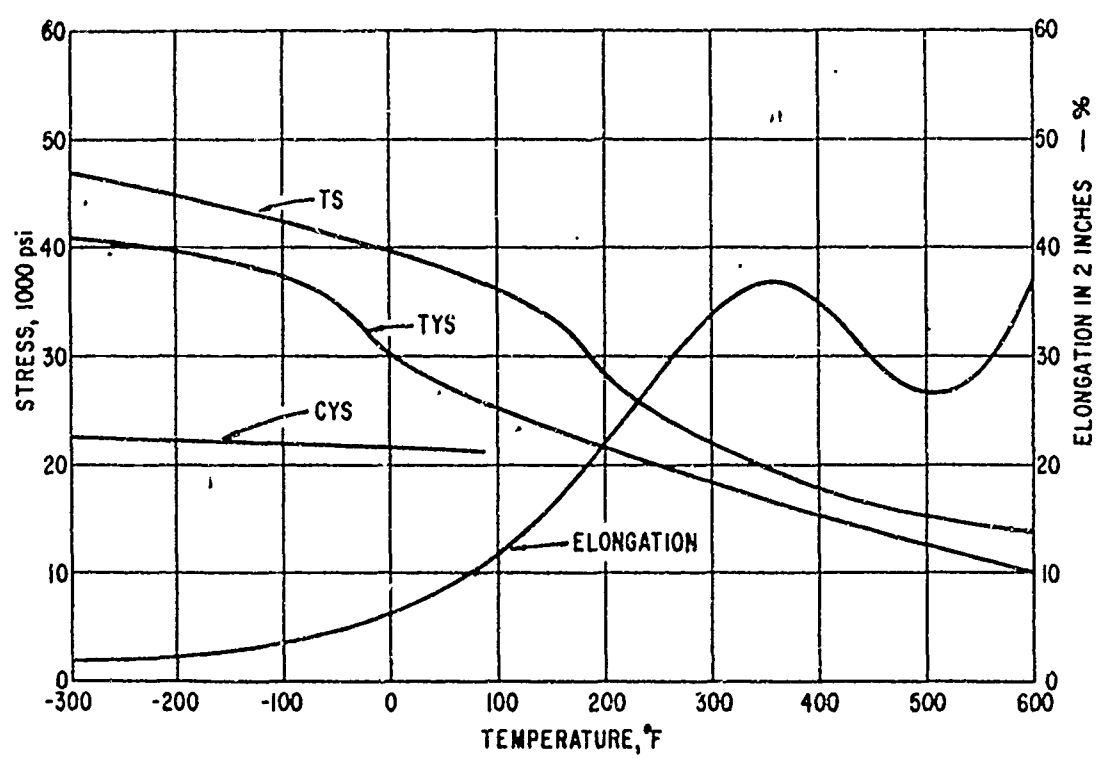


FIG. No. 4-2 Effect of Temperature on Properties of HK31A 1/2" Plate—limited data  
(sub zero data by Case Institute of Technology)

DATA FROM WADC REPORT 58-386

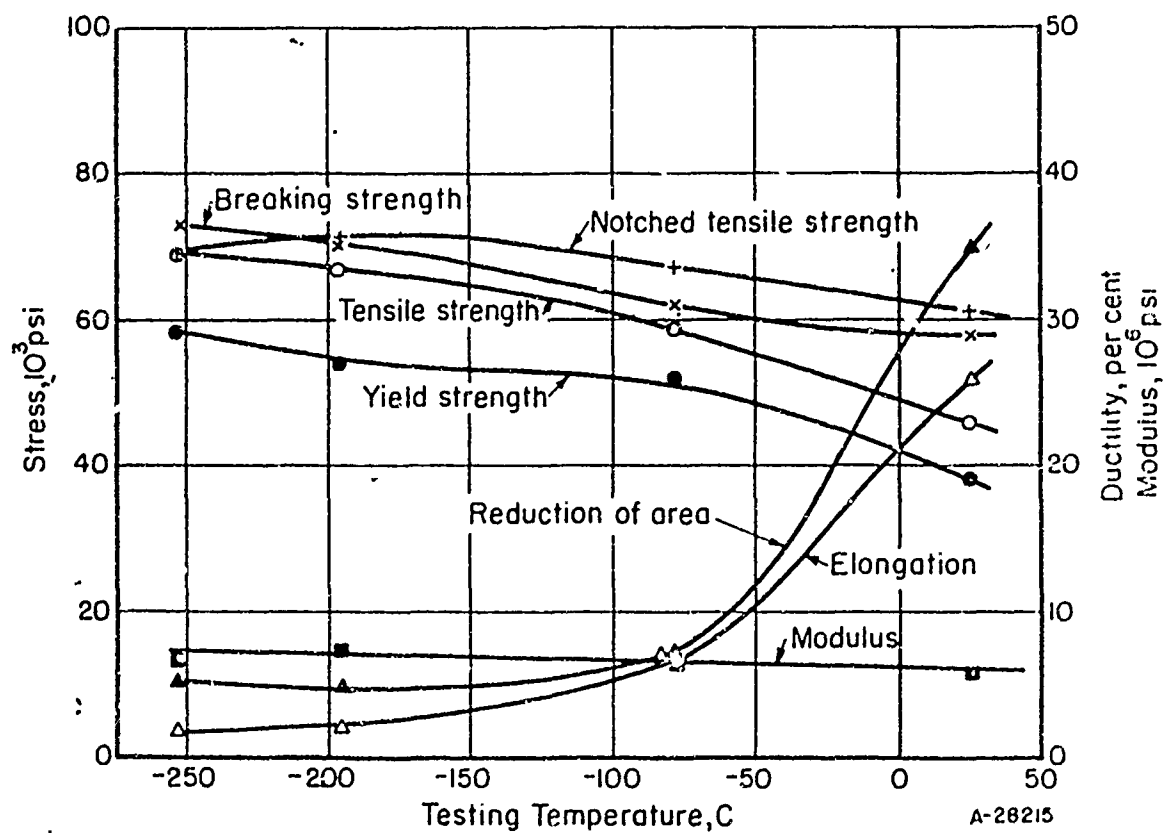


FIGURE 43 MECHANICAL PROPERTIES OF EXTRUDED ZK60A-T5 MAGNESIUM-ALLOY BAR

Figure 14  
YIELD AND TENSILE STRENGTHS OF MAGNESIUM ALLOYS  
AT LOW TEMPERATURES

Data from McAdam, Mebs, &  
Geil  
ASTM, Vol 44, 1944

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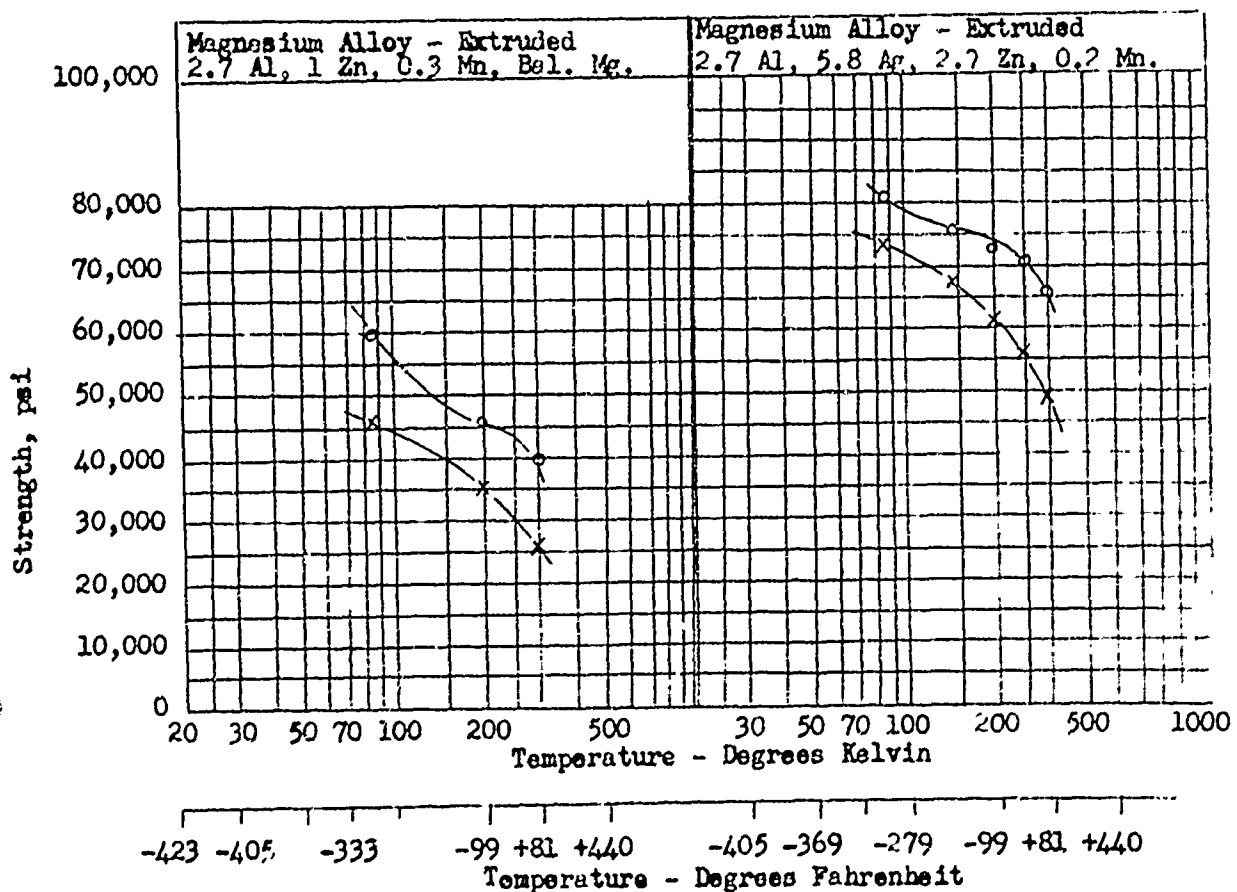
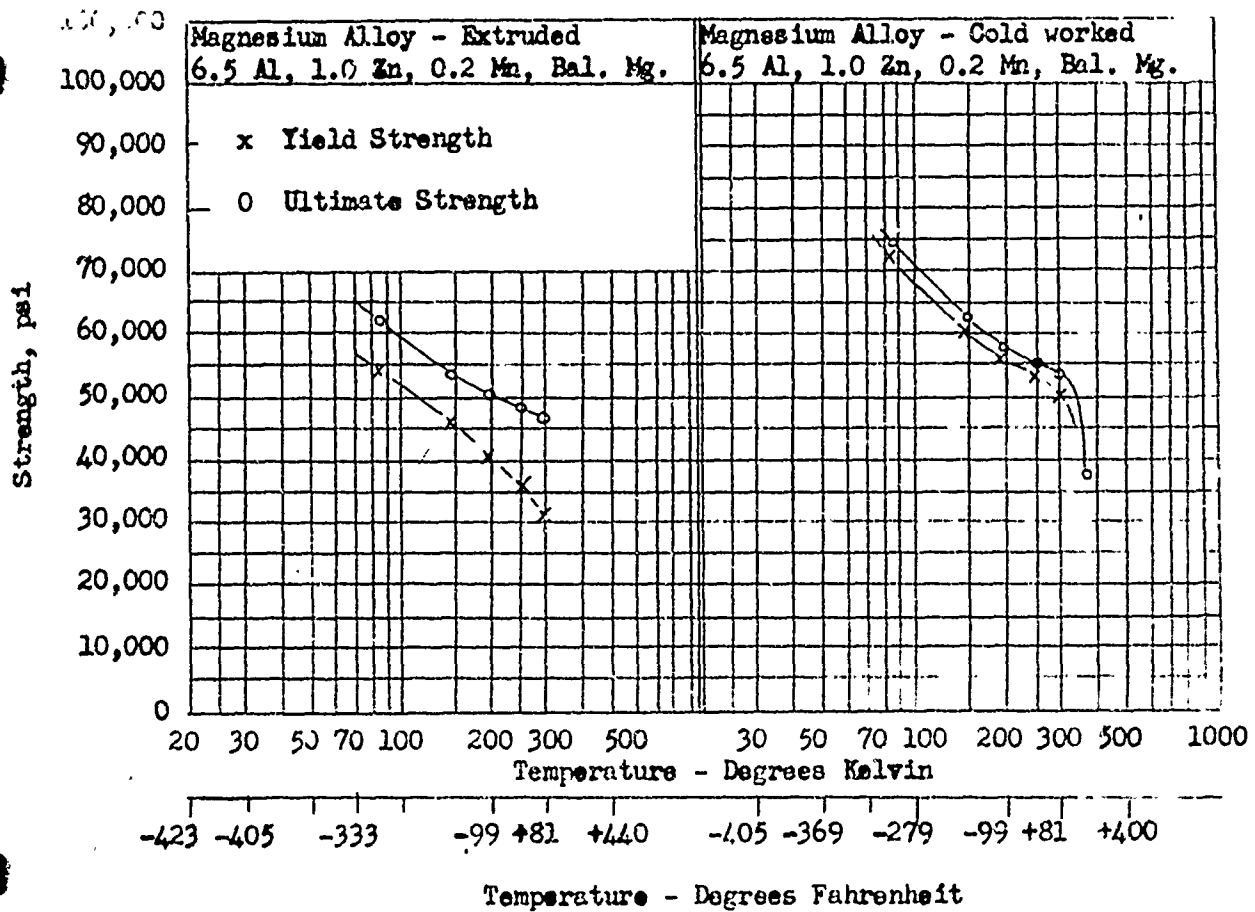
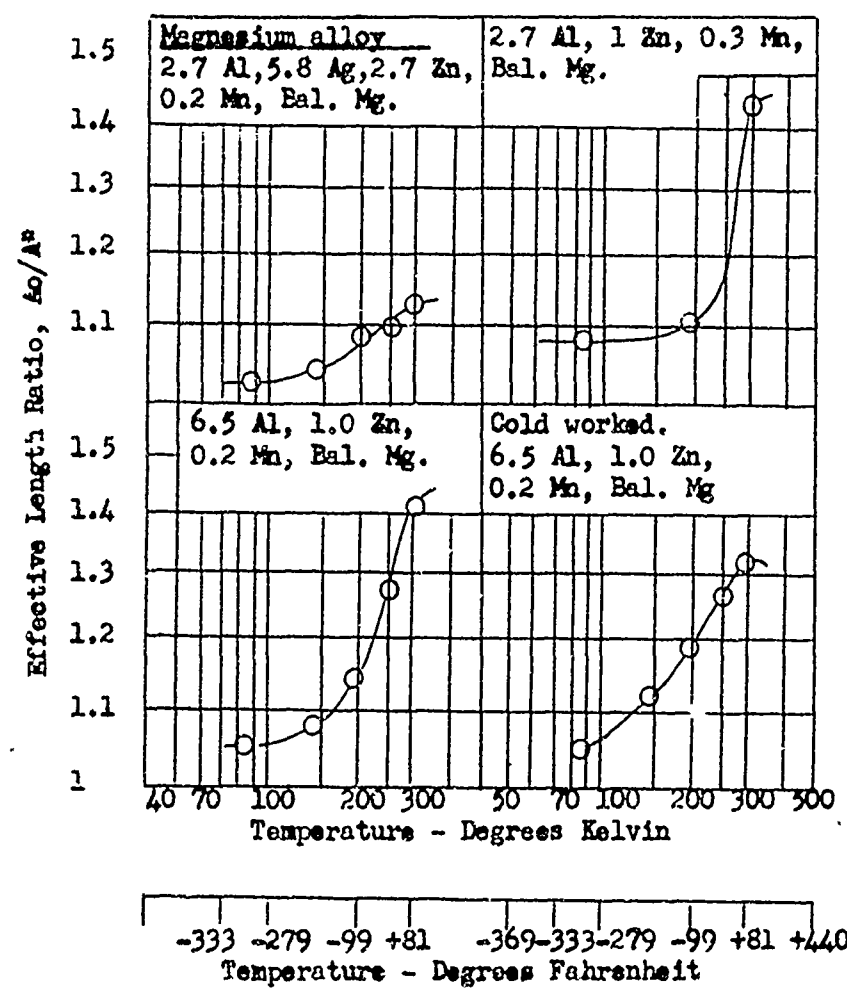


FIGURE 45  
 DUCTILITY OF MAGNESIUM ALLOYS  
 AT LOW TEMPERATURES



Data from McAdam, Mabe, & Geil  
 ASTM, Vol 44, 1944

\* $A_0$  represents the initial cross sectional area and  $A$  the cross sectional area at moment of rupture.

TABLE XI  
LOW TEMPERATURE DATA OF MAGNESIUM ALLOYS

<u>Alloy and</u> <u>Temper</u>	<u>Temperature</u> <u>°F</u>	<u>TS</u> <u>kai</u>	<u>T<sub>TS</sub></u> <u>kai</u>	<u>Elong.</u> <u>% in 2"</u>	<u>References</u>
HK31A-H24	+75	36.3	29.0	7.5	Dow*
"	-65	43.3	32.0	5.0	Dow
"	-98	42.7	30.6	4.2	Dow
"	-320	54.0	33.0	6.2	Dow
AZ31B-F	+77	40.1	29.9	16.5	1
"	-108	45.6	39.8	15.0	1
"	-314	62.8	48.4	6.5	1
"	+79	39.5	26		2
"	-108	45.5	35.5		2
"	-306	59.5	46		2
AZ61A-F	RM	47	34	13	3
"	-108	50	41	12	3
"	RM	41.8	30.4	13	4
"	-110	44.6	36.6	12	4
"	RM	44		15	4
"	-112	46		8	4
"	RM	39.6	28.0	13	4
"	-76	42.8	33.2	10	4
"	RM	40	26	15	5
"	-112	50	40	11	5
"	-310	55	48	4	5
HM31XA-F	+75	40.5	36.6	13.5	Dow
"	-65	48.4	40.2	7.5	Dow
"	-98	48.3	38.6	4.5	Dow
"	-320	57.5	44.8	5.5	Dow

\* The Dow data are the average of two tests.  
 Data from Dow Chemical Company.

DATA FROM NBS REPORT 5505 BY McCLINTOCK, VAN GURDY,  
AND KHOPSCHOT

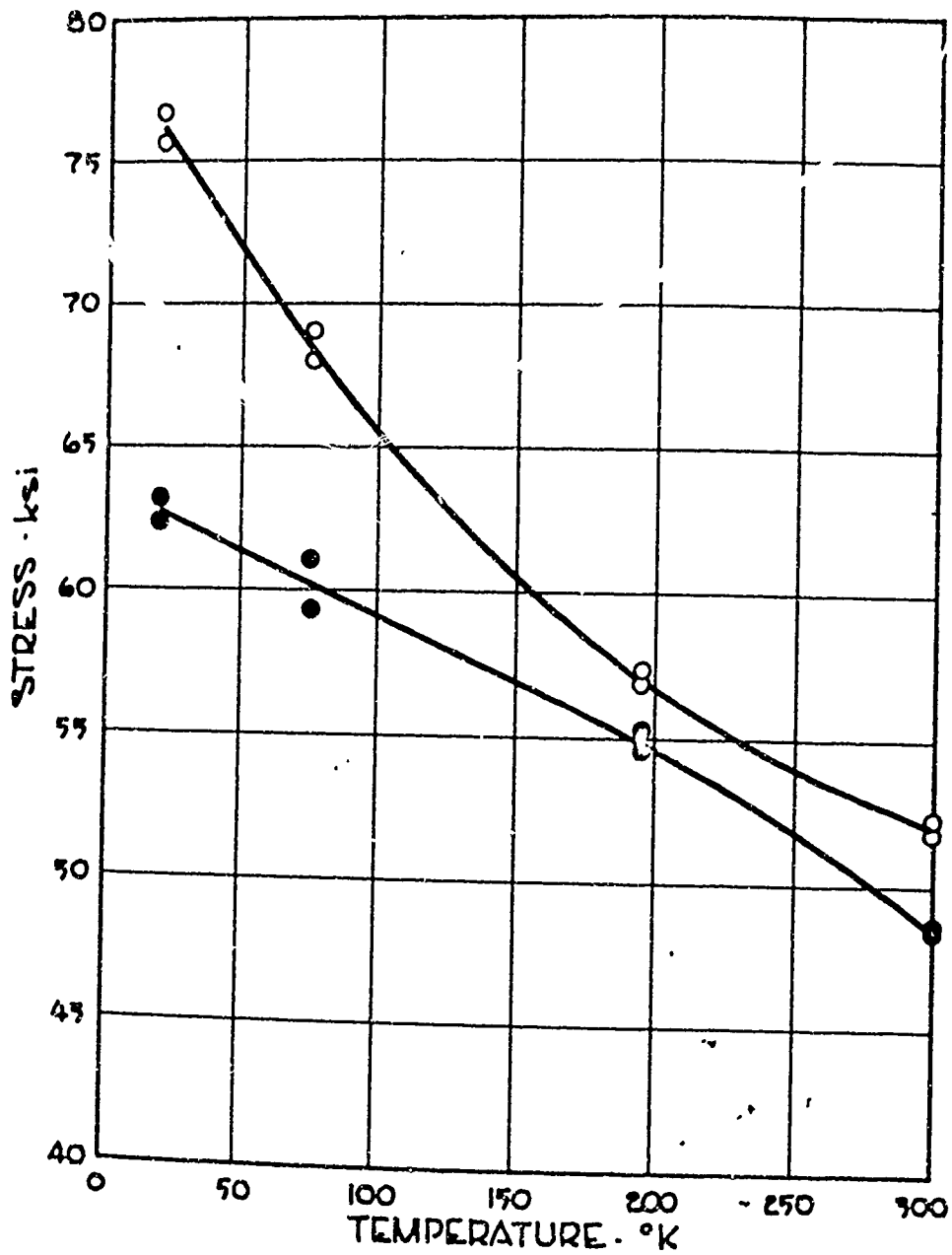
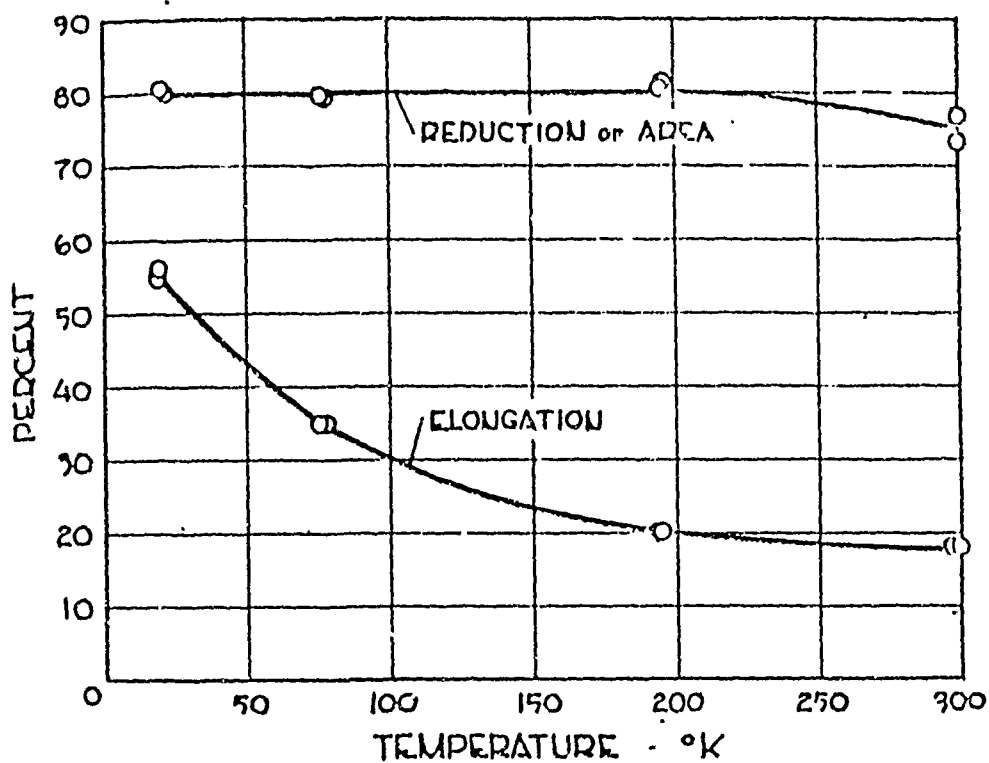


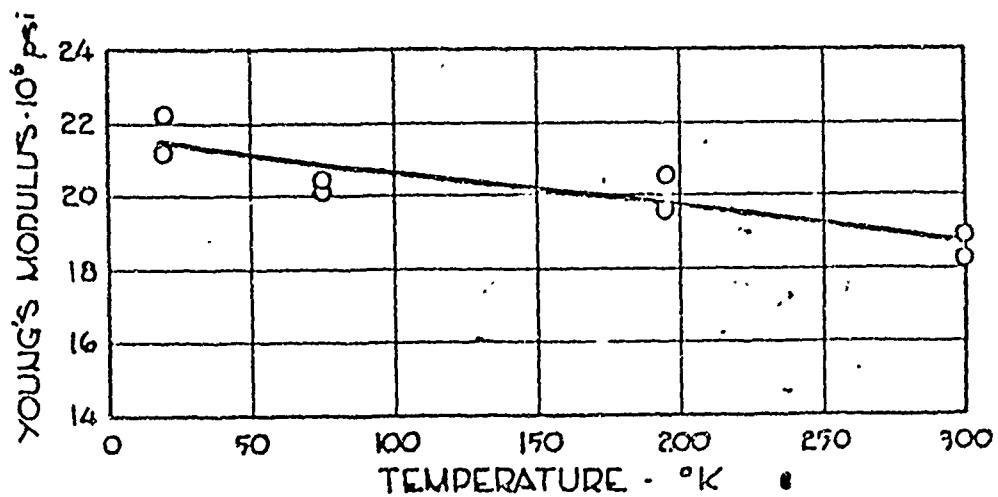
Figure 24.6 Tensile and yield strength (.002 offset) vs. temperature, OFHC copper bar, 40% cold drawn.

DATA FROM NBS REPORT 5505 BY McCLINTOCK, VAN GURDY,  
AND KROISCHOT.

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Percent elongation in 1 inch and reduction of area vs. temperature of OFHC copper bar, 40% cold drawn.



Young's modulus vs. temperature of OFHC copper bar, 40% cold drawn.

FIGURE 47

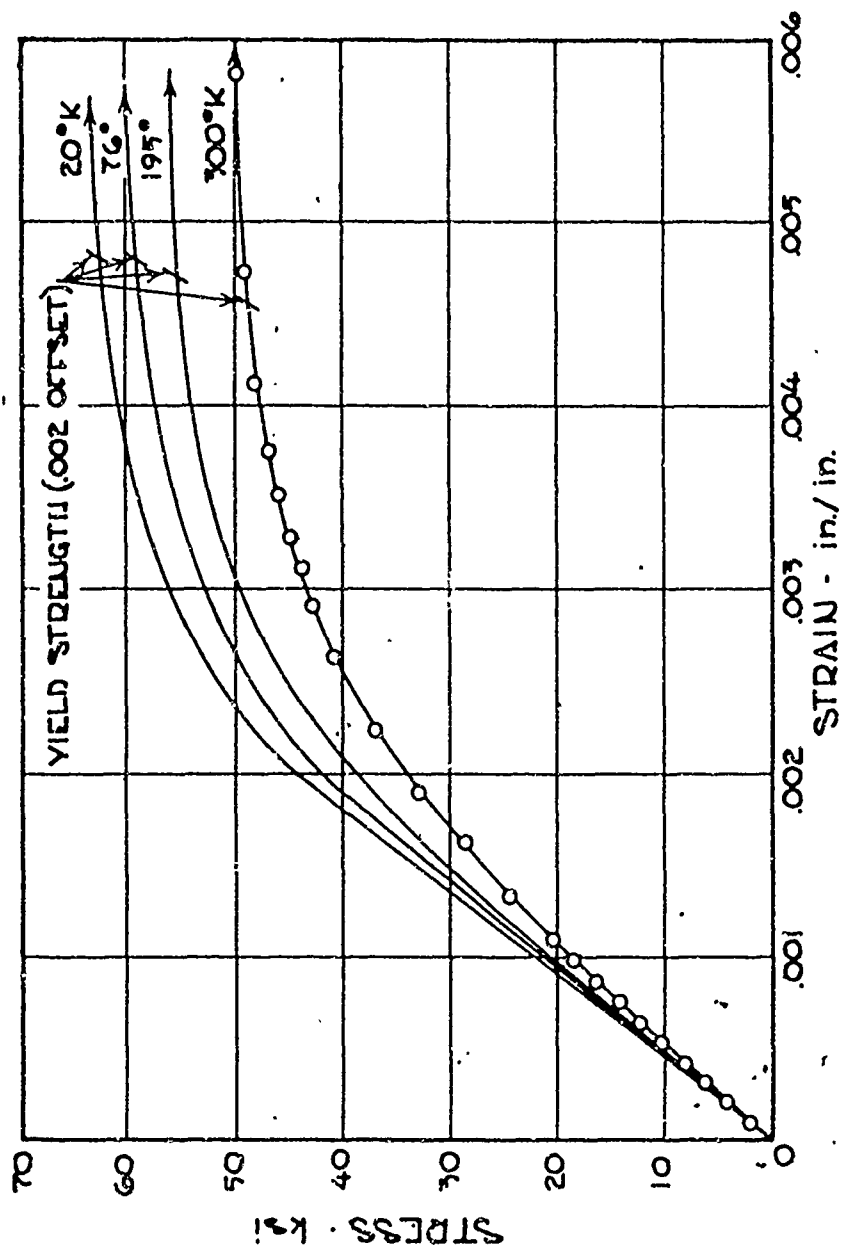


Figure 48. Typical stress-strain curves for OFHC copper bar - 40% cold drawn.  
 Data from NBS Report 5505 by McClintock, Van Gurdy, and Knapton.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KROPSCHOT

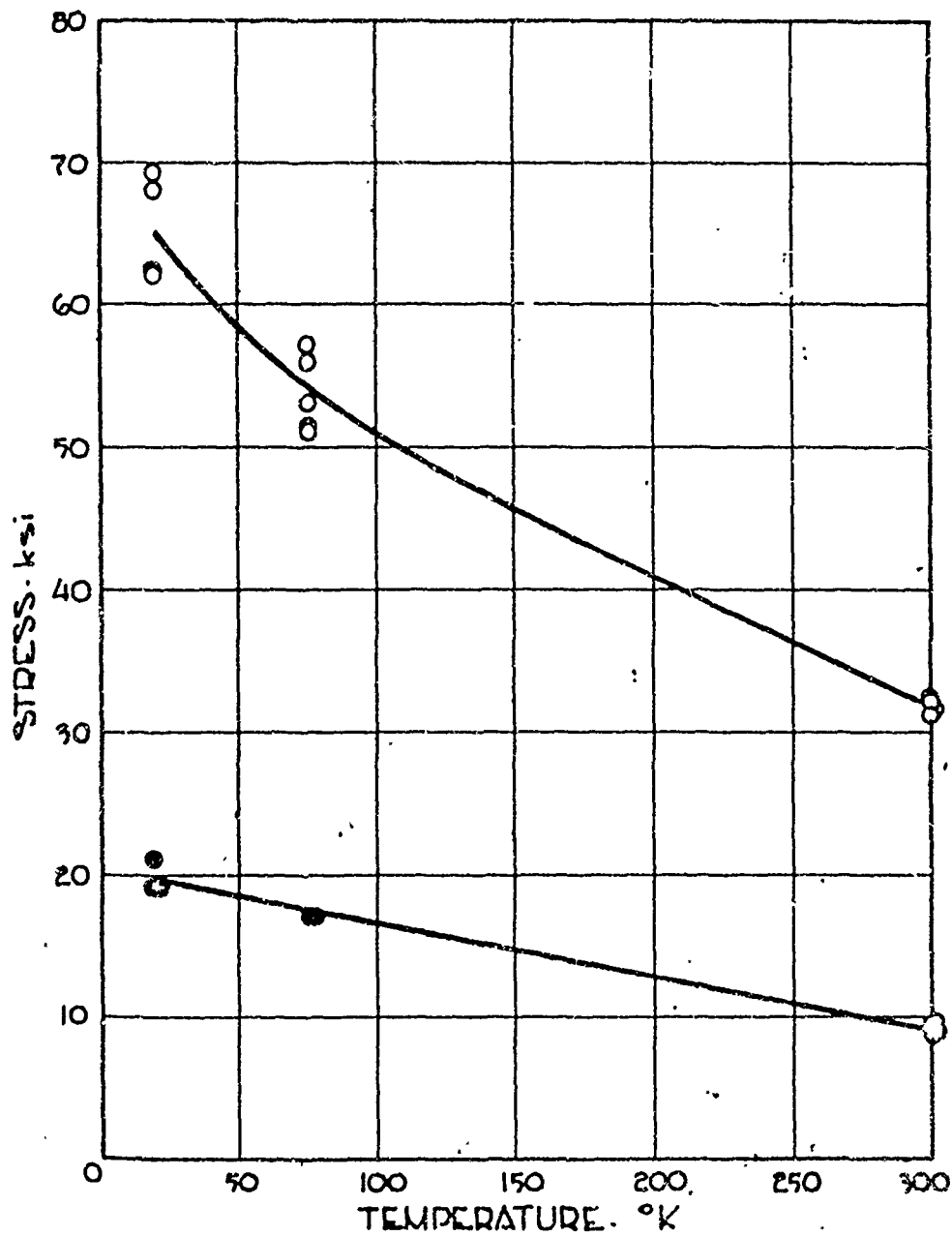


Figure 49. Tensile and yield strength (0.001 offset) of 0.010" copper foil pulled parallel to direction of rolling.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KROPSCHOT

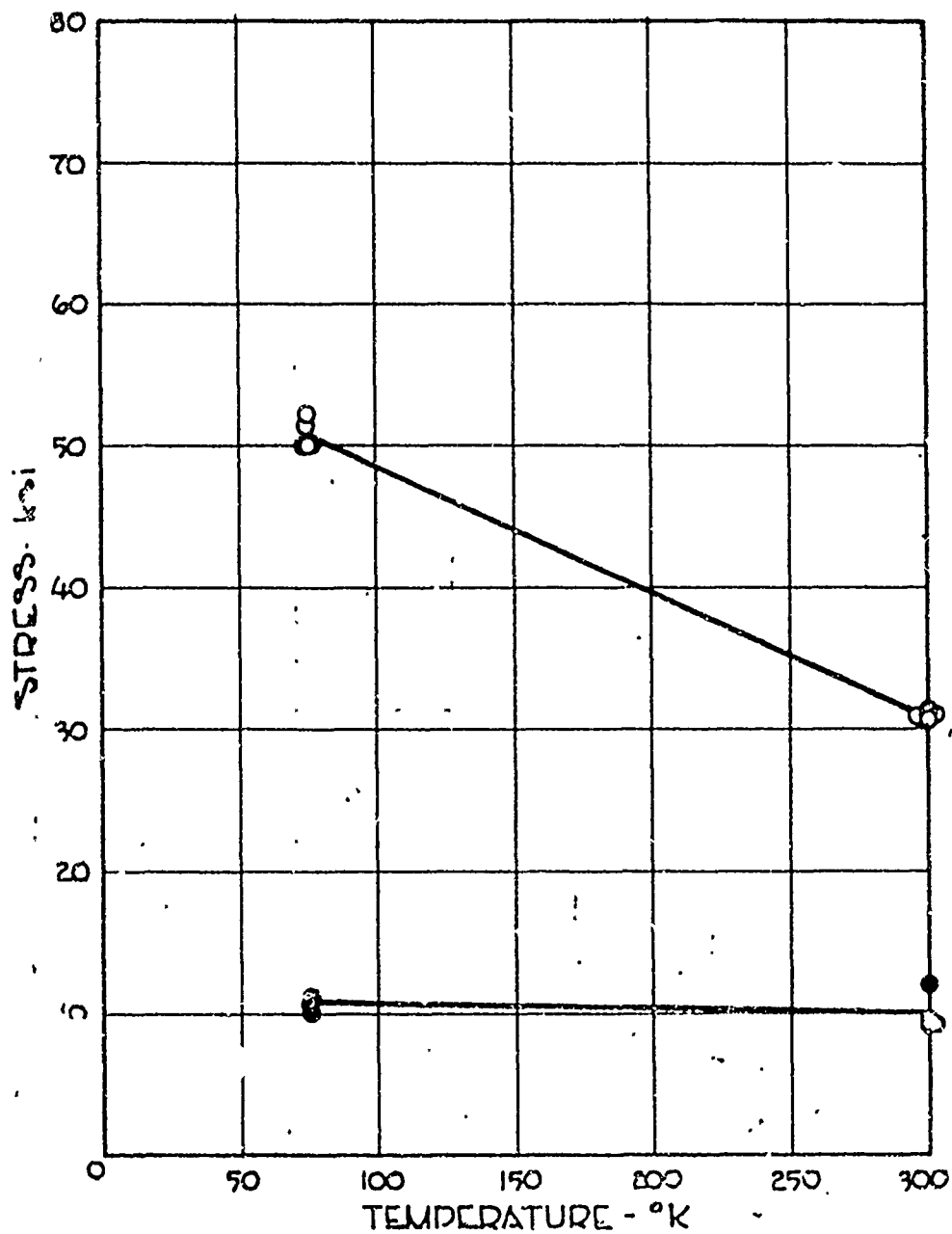
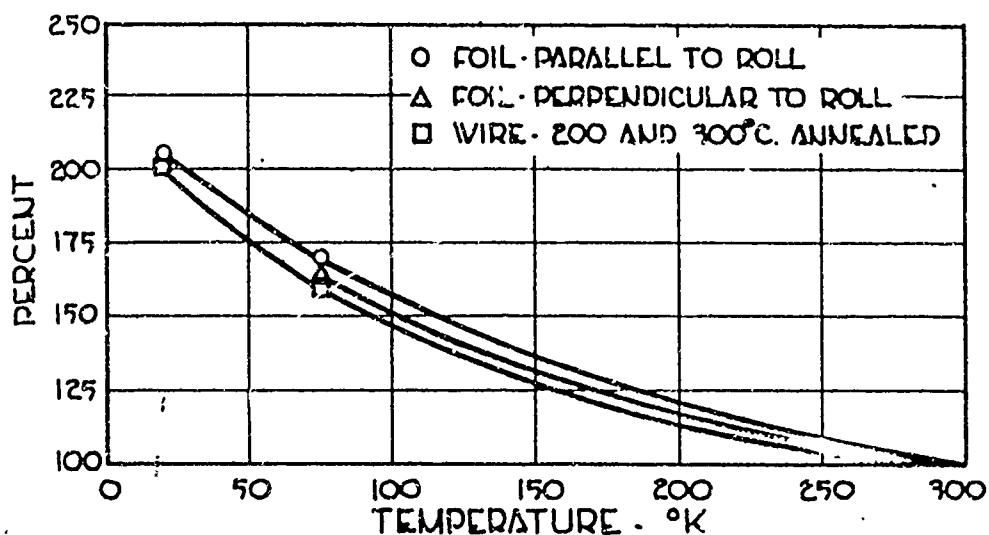


Figure 50. Tensile and yield strength (0.001 offset) of 0.010" copper foil pulled perpendicular to direction of rolling.



Percent of room temperature tensile strength vs. temperature for OFHC copper foil and wire.

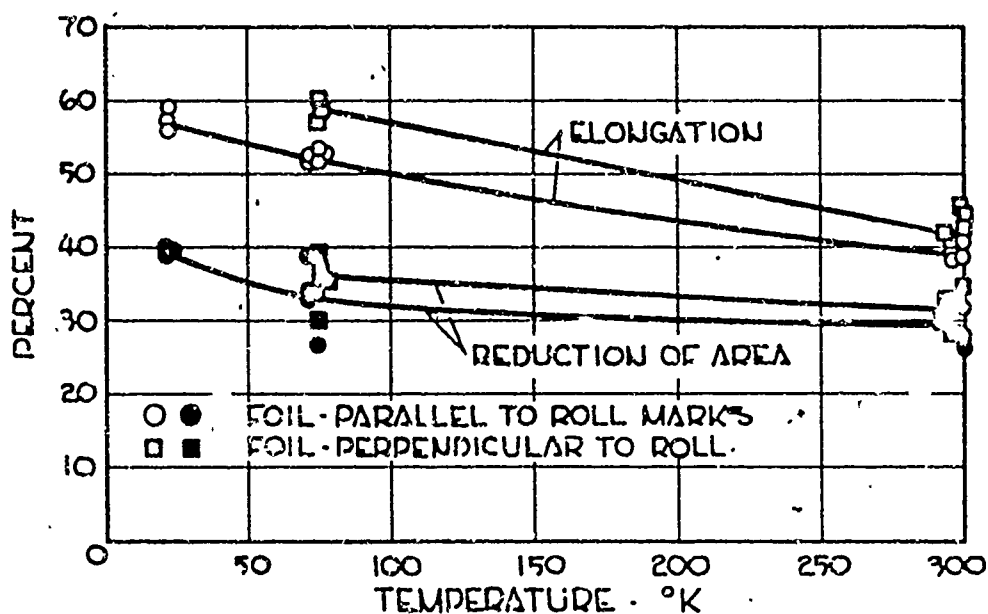


Figure 51. Percent elongation in 2 inches and reduction of area vs. temperature of 0.010" copper foil.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GORDY  
AND KROPSCHOT

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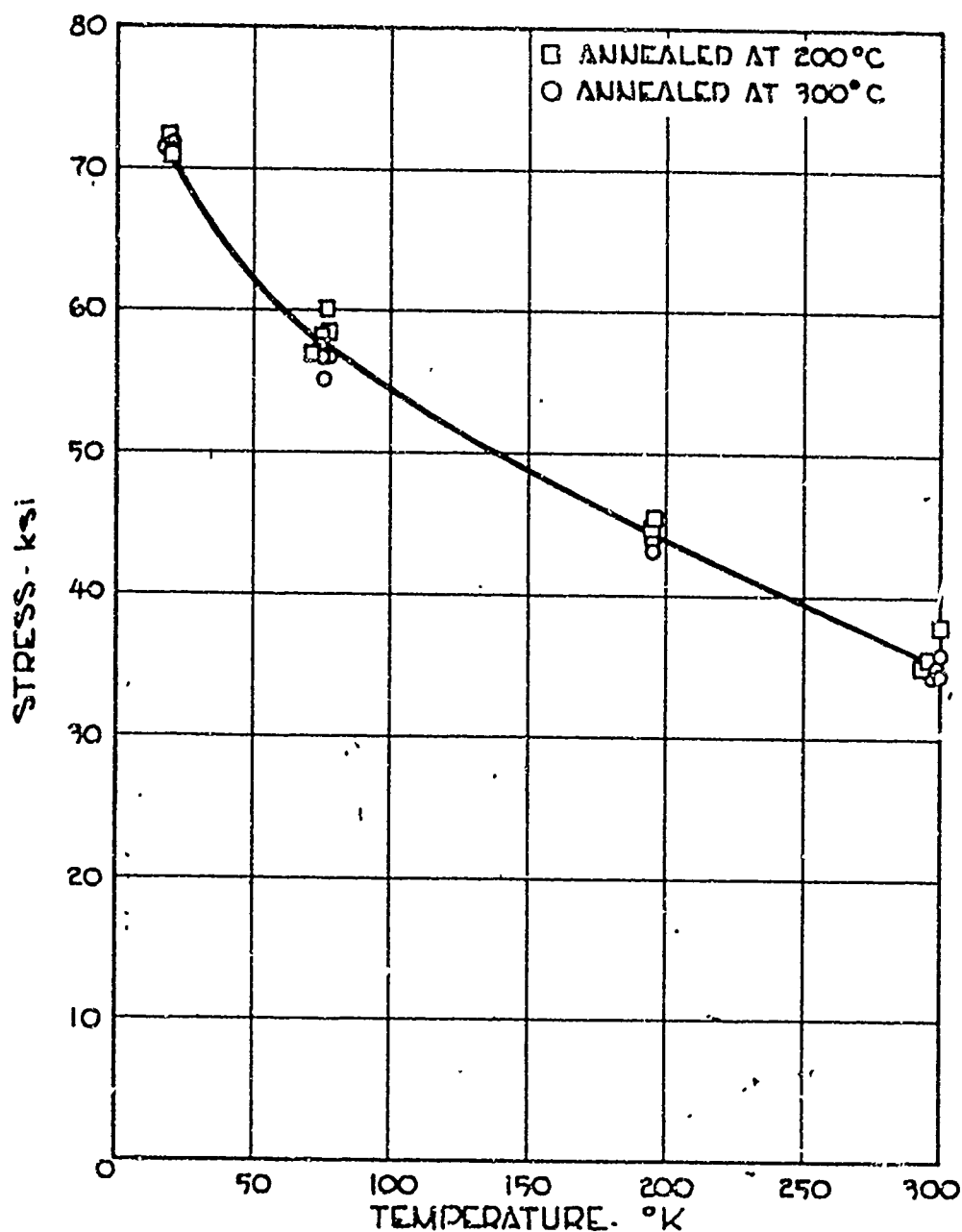


Figure 52. Tensile strength of OFHC copper wire vs. temperature.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KHOPSCHOT

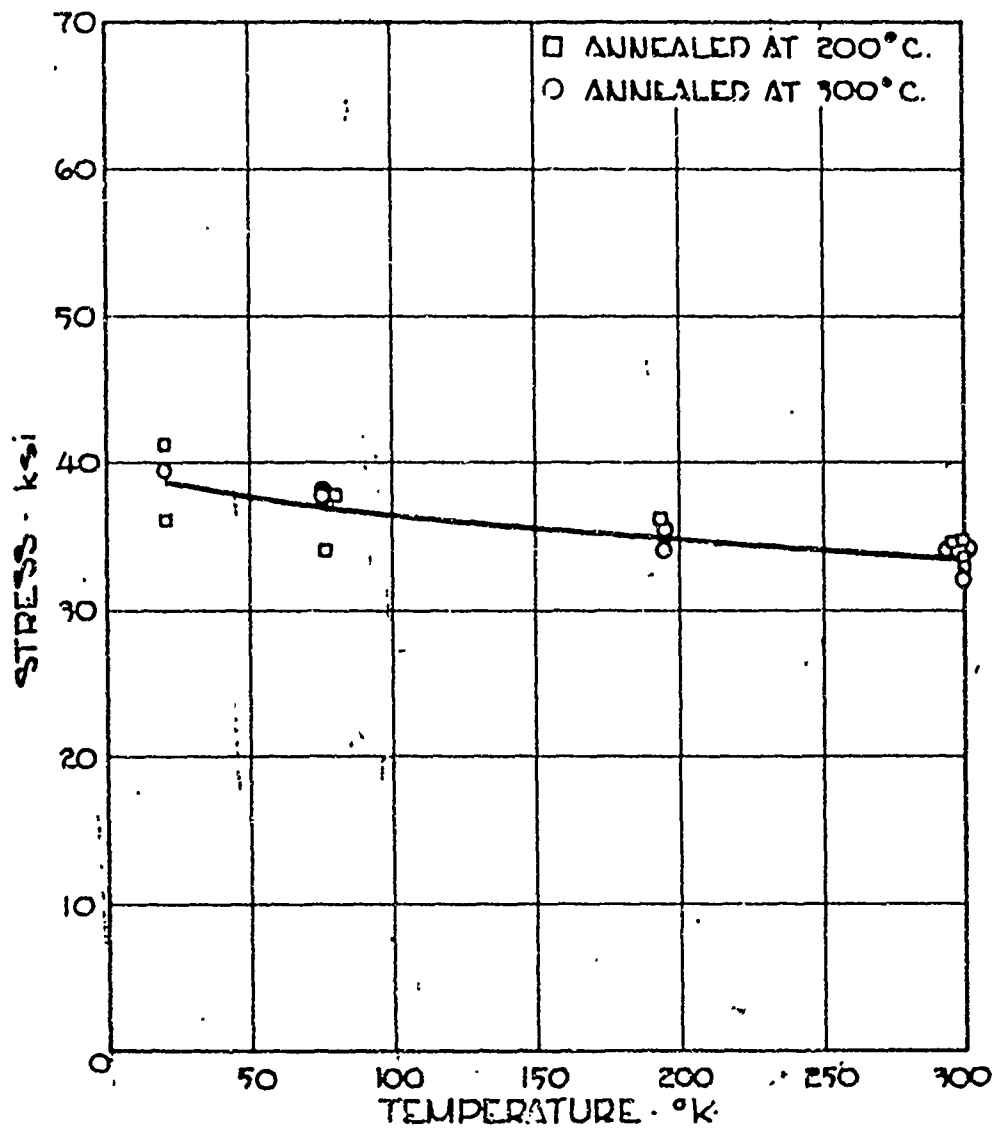
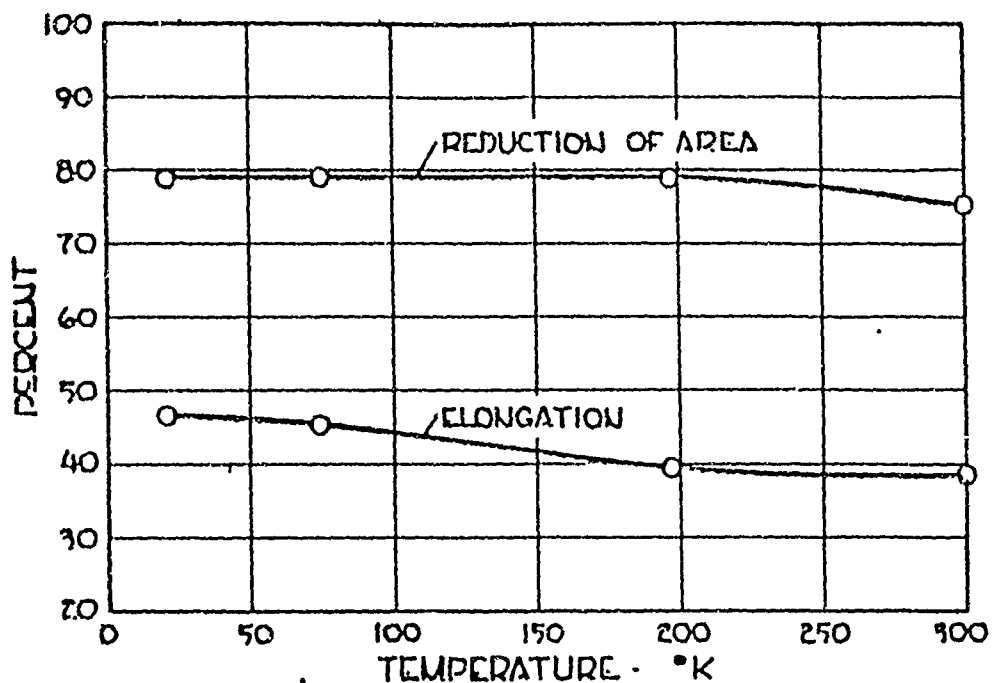


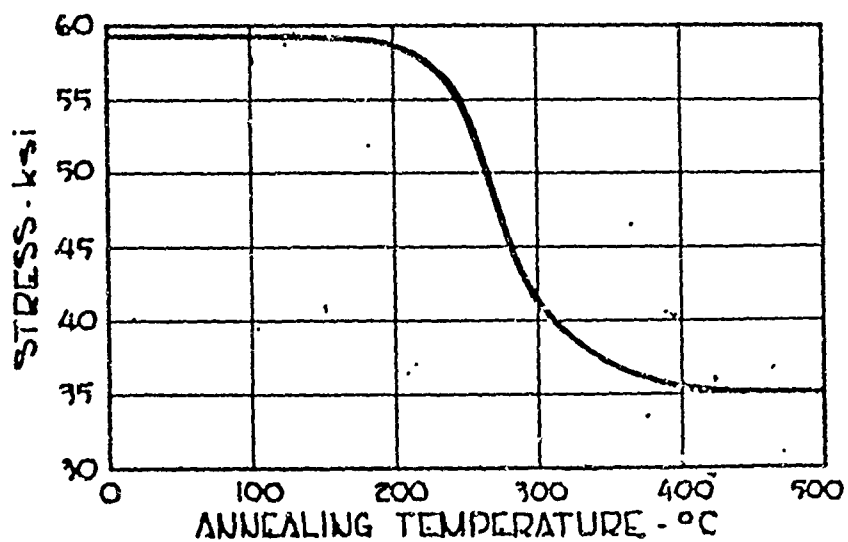
Figure 33 "Yield strength" of OFHC copper wire vs. temperature.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KROPSCHOT

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Percent elongation and reduction of area vs. temperature  
of OFHC copper wire.



Ultimate strength vs. annealing temperature of OFHC  
copper. [5]

FIGURE 54

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KROPSCHOT

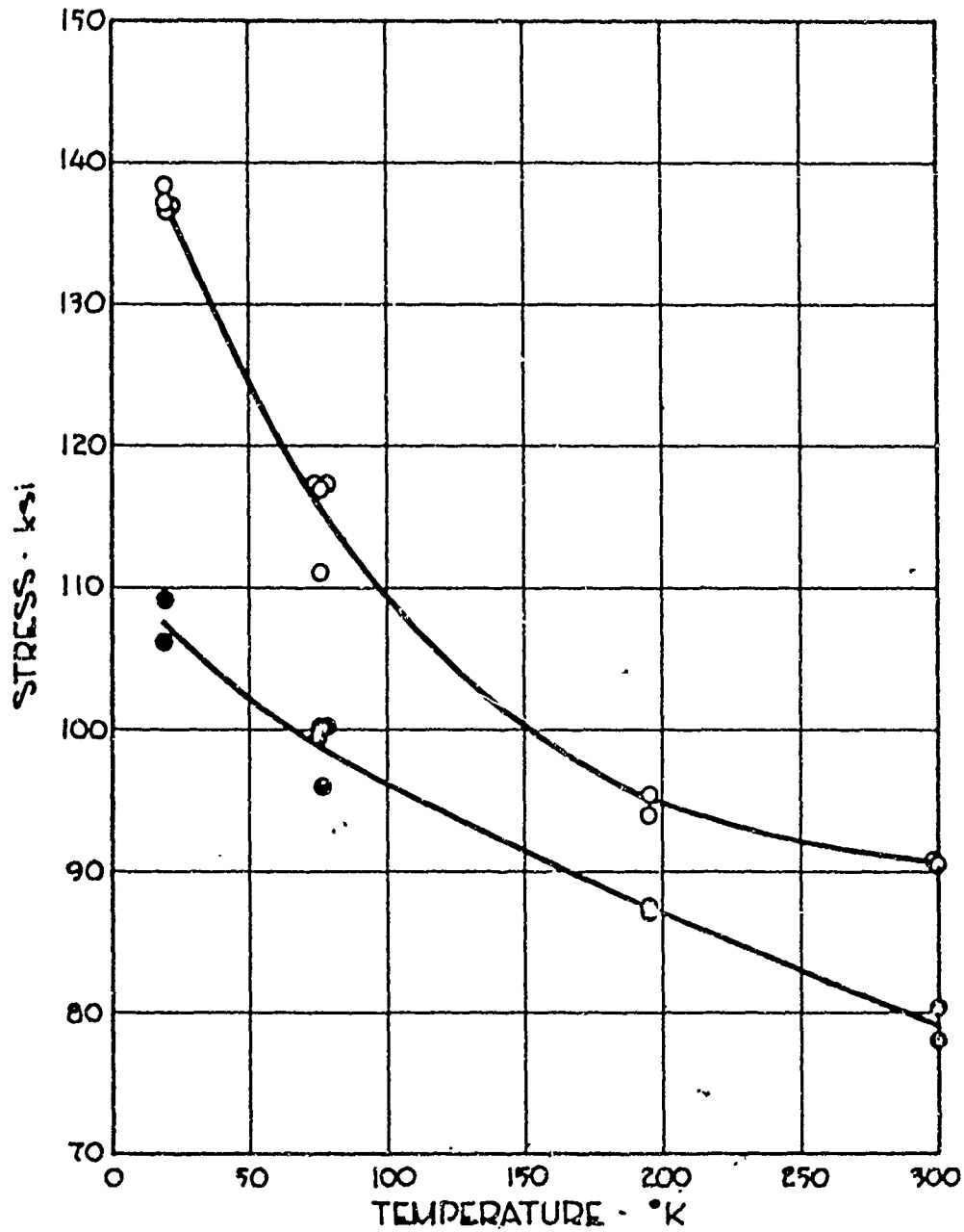
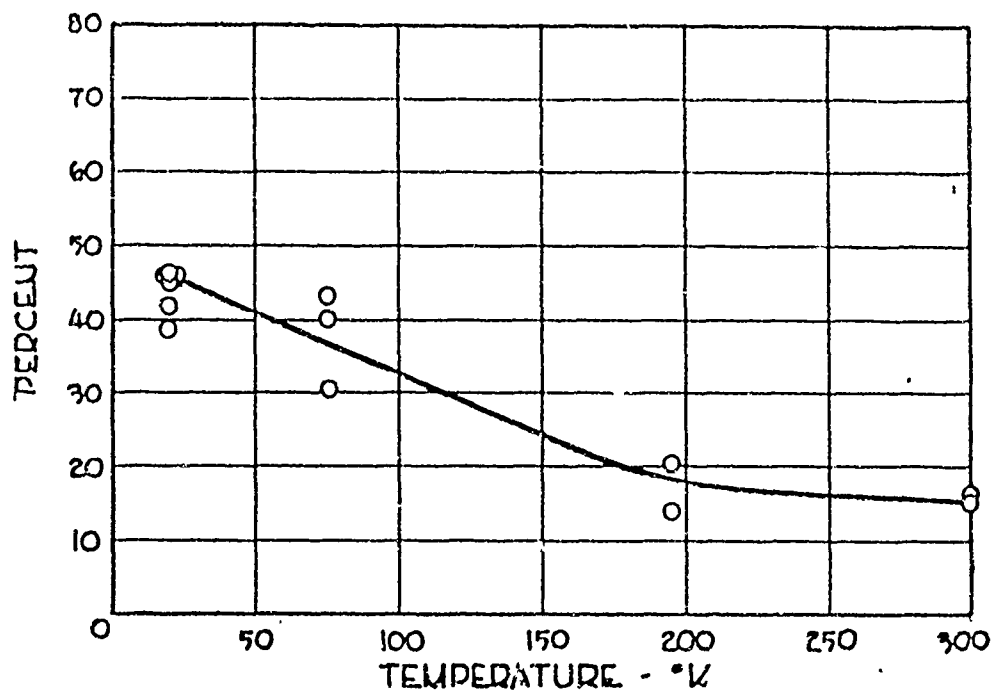


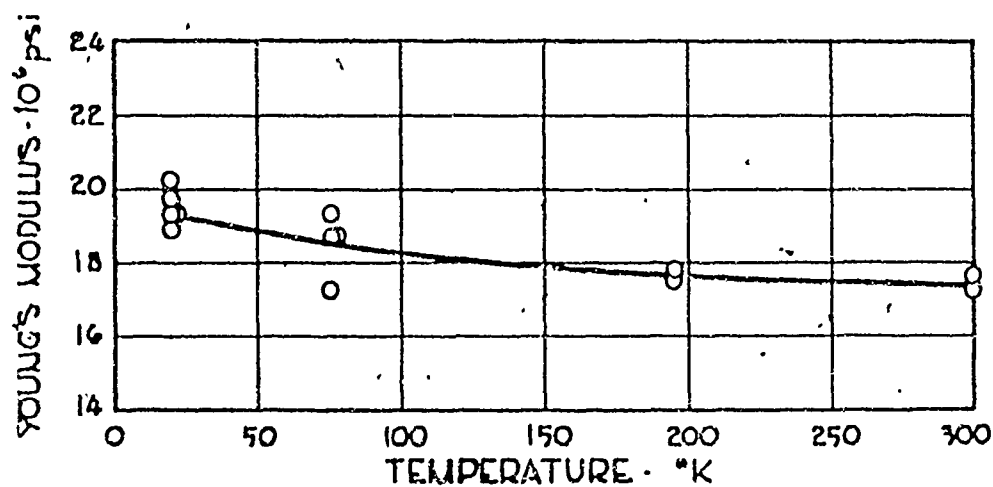
Figure 55. Tensile and yield strength (.002 offset) vs. temperature of Berylco 25, 1/2 hard.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KHOPECHOT

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Percent elongation in 2 inches vs. temperature of  
Berylco 25, 1/2 hard.



Young's modulus vs. temperature of Berylco 25, 1/2 hard.

FIGURE 56

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DATA FROM NPS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KROPSCHOT

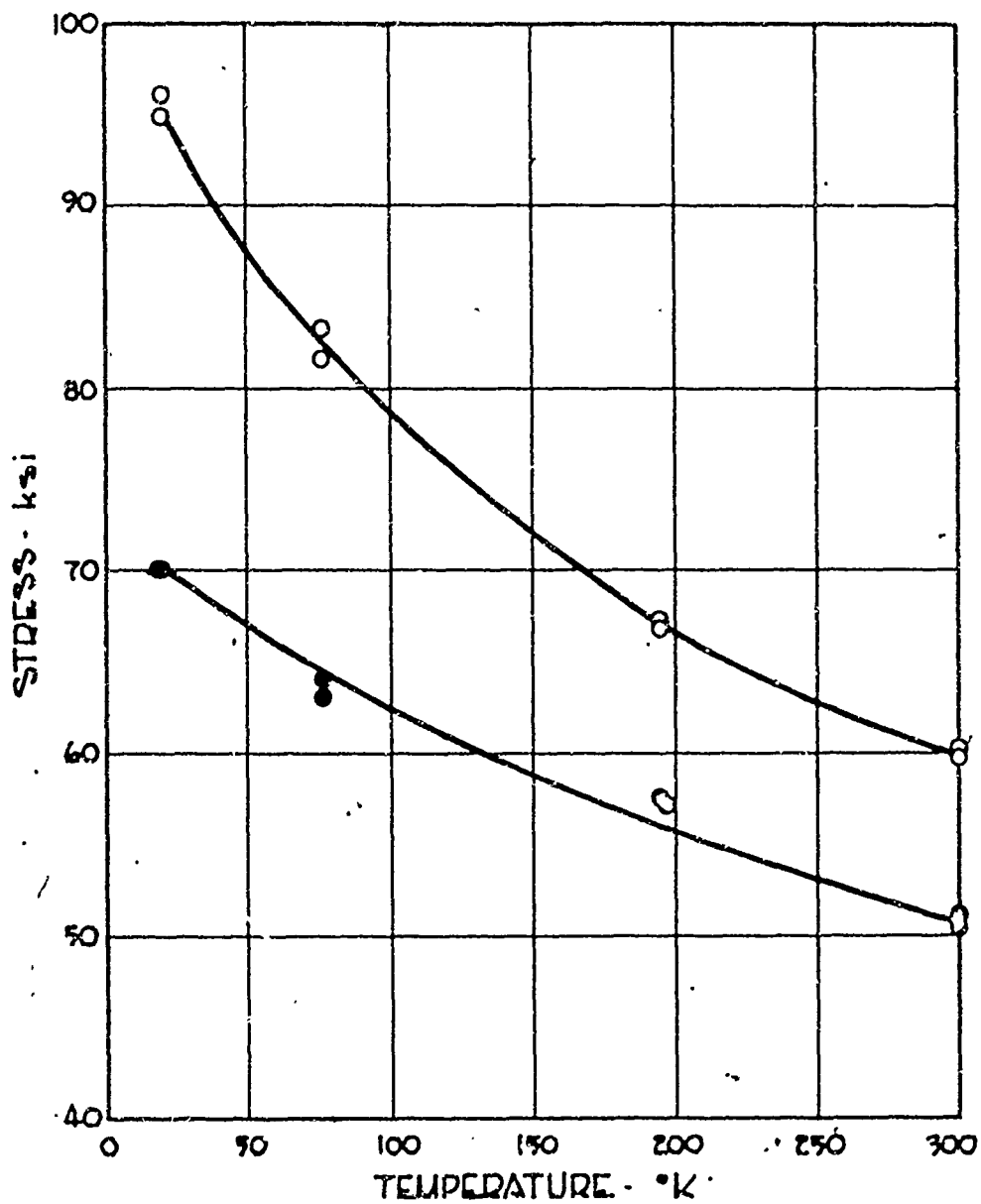
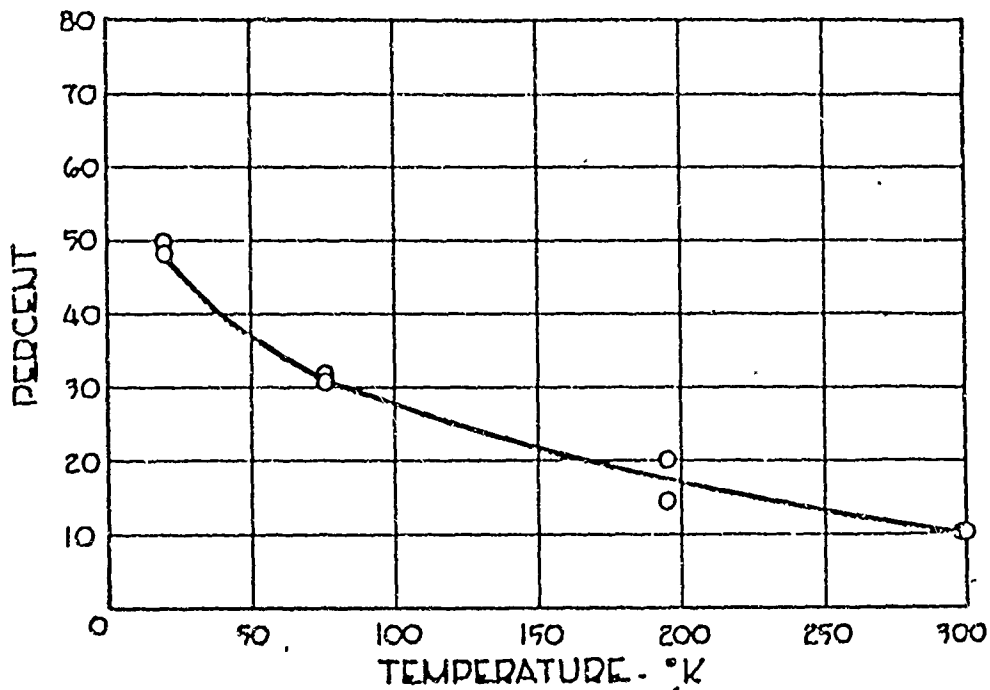
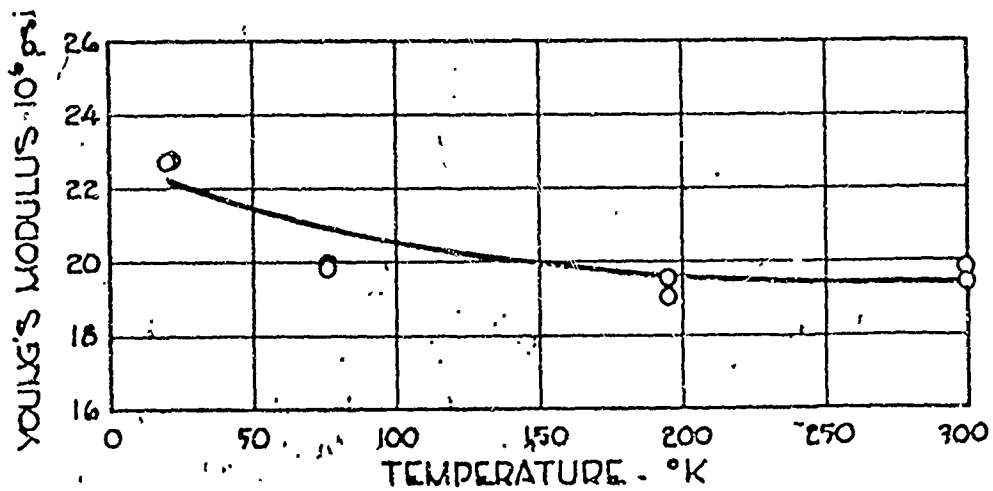


Figure 57 Tensile and yield strength (.002 offset) vs. temperature  
of Berylco 10, 1/2 hard.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KHOPSCHOT



Percent elongation in 2 inches vs. temperature of  
Berylco 10, 1/2 hard.



Young's modulus vs. temperature of Berylco 10, 1/2 hard.

FIGURE 58

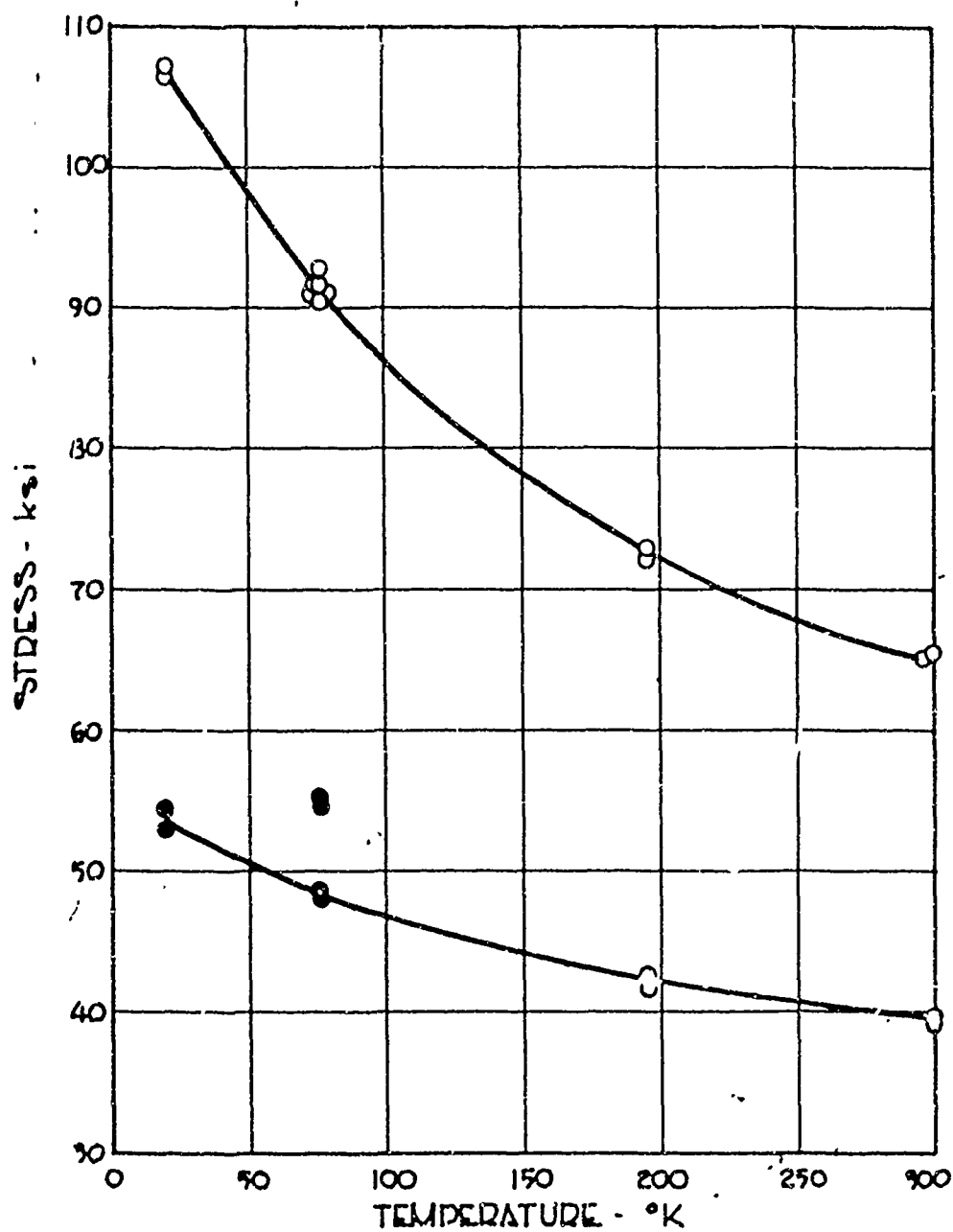
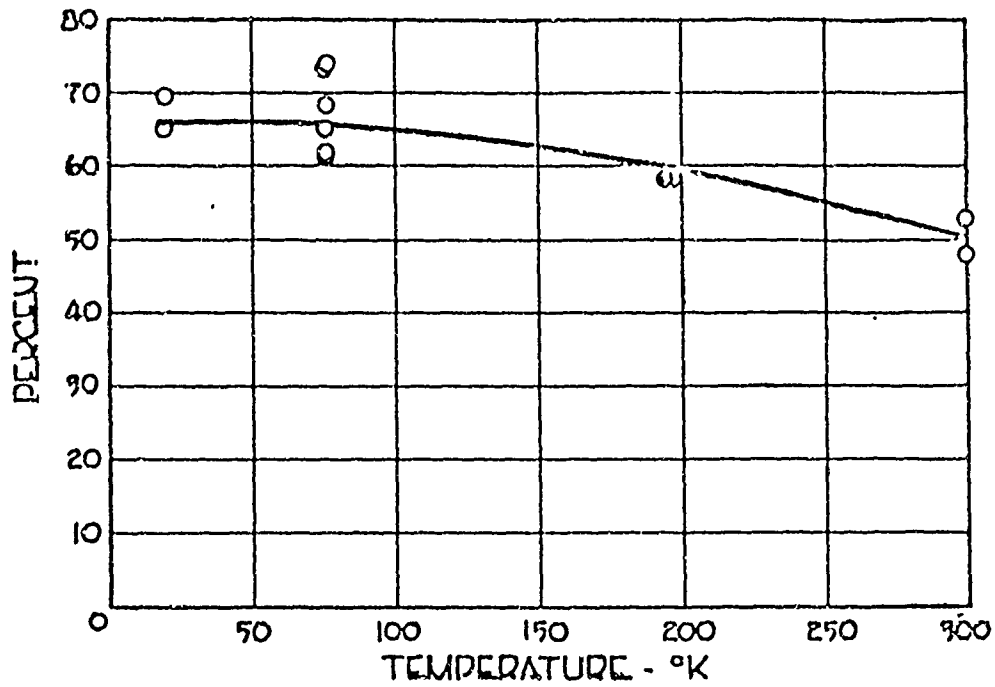
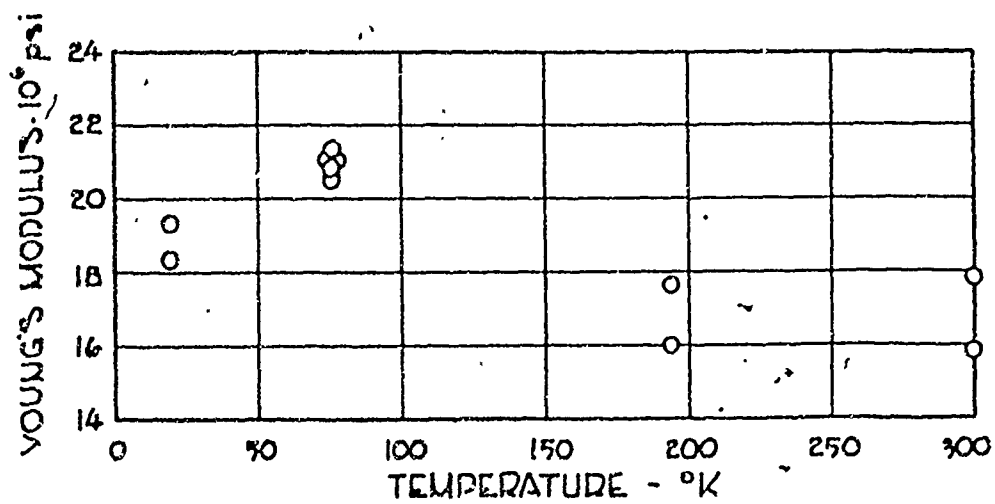


Figure 59. Tensile and yield strength (.002 offset) vs. temperature of Everdur 1010, 1/4 hard.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KROFECROT



Percent elongation in 2 inches vs. temperature of Everdur  
1010, 1/4 hard.



Young's modulus vs. temperature of Everdur 1010,  
1/4 hard.

DATA FROM NBS REPORT 5505, BY McCLINTOCK, VAN GURDY  
AND KROPSCHOT

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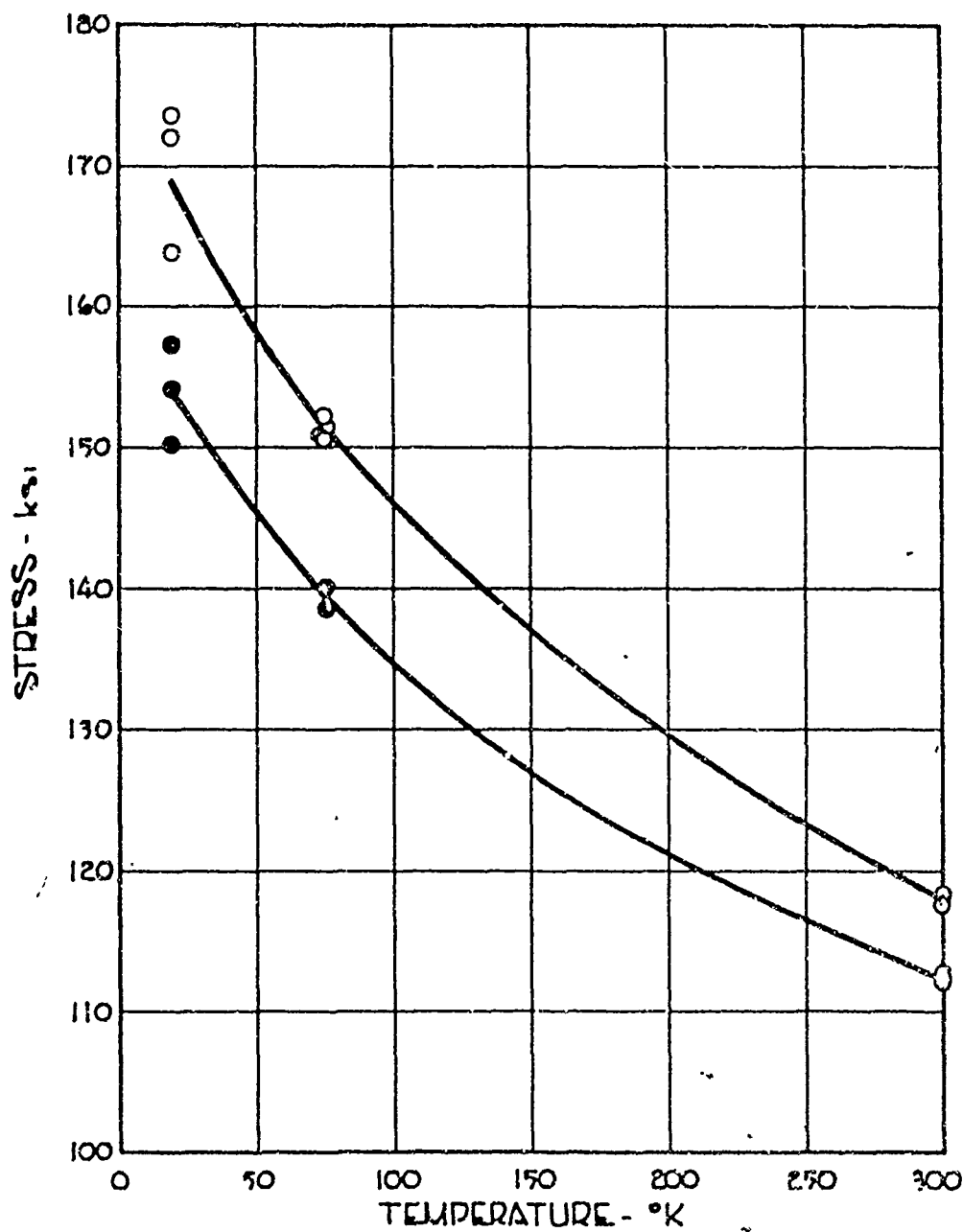
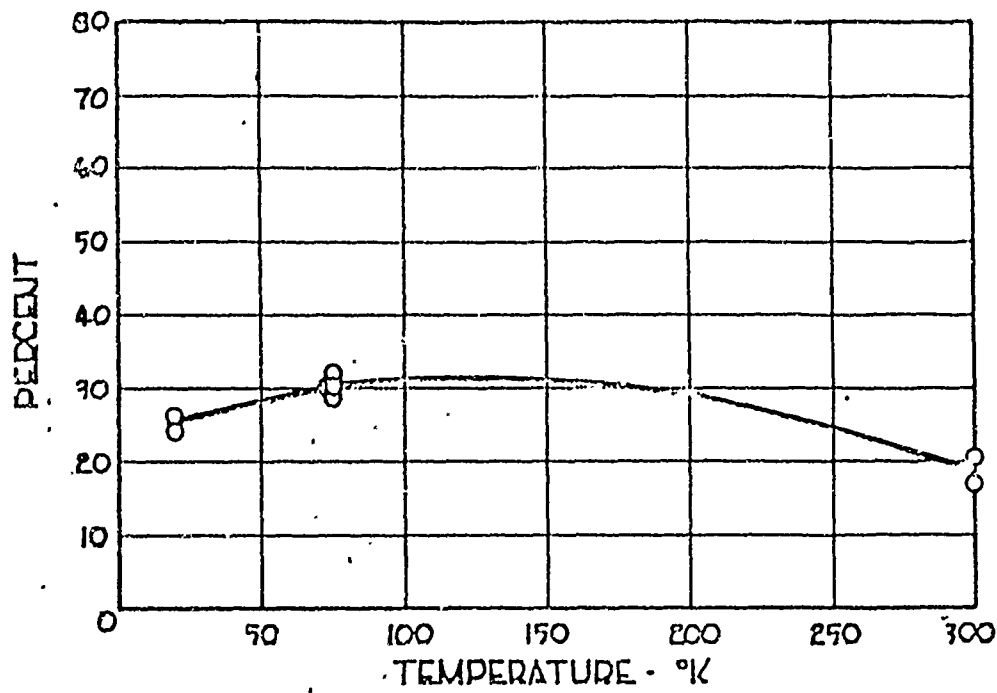
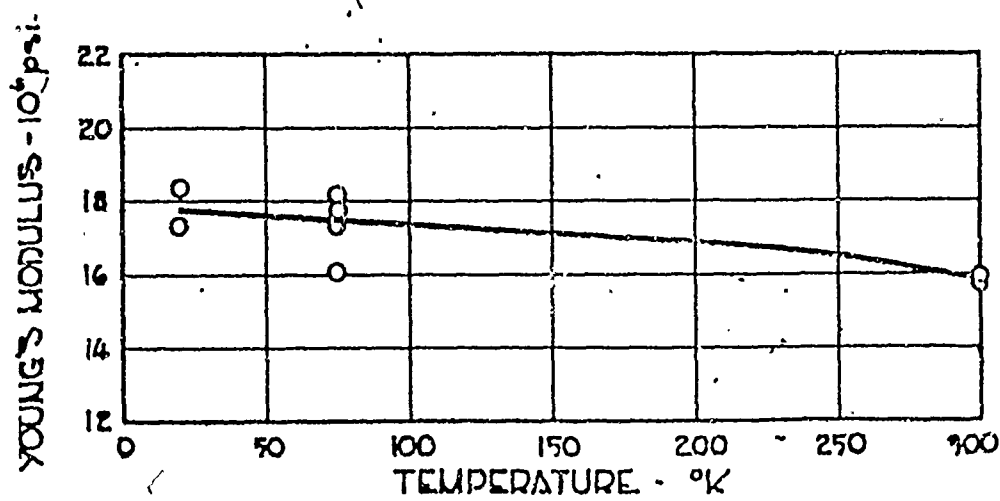


Figure 44 Tensile and yield strength (.002 offset) vs. temperature of phosphor bronze, hard.



Percent elongation in 1 inch vs. temperature of phosphor bronze, hard.

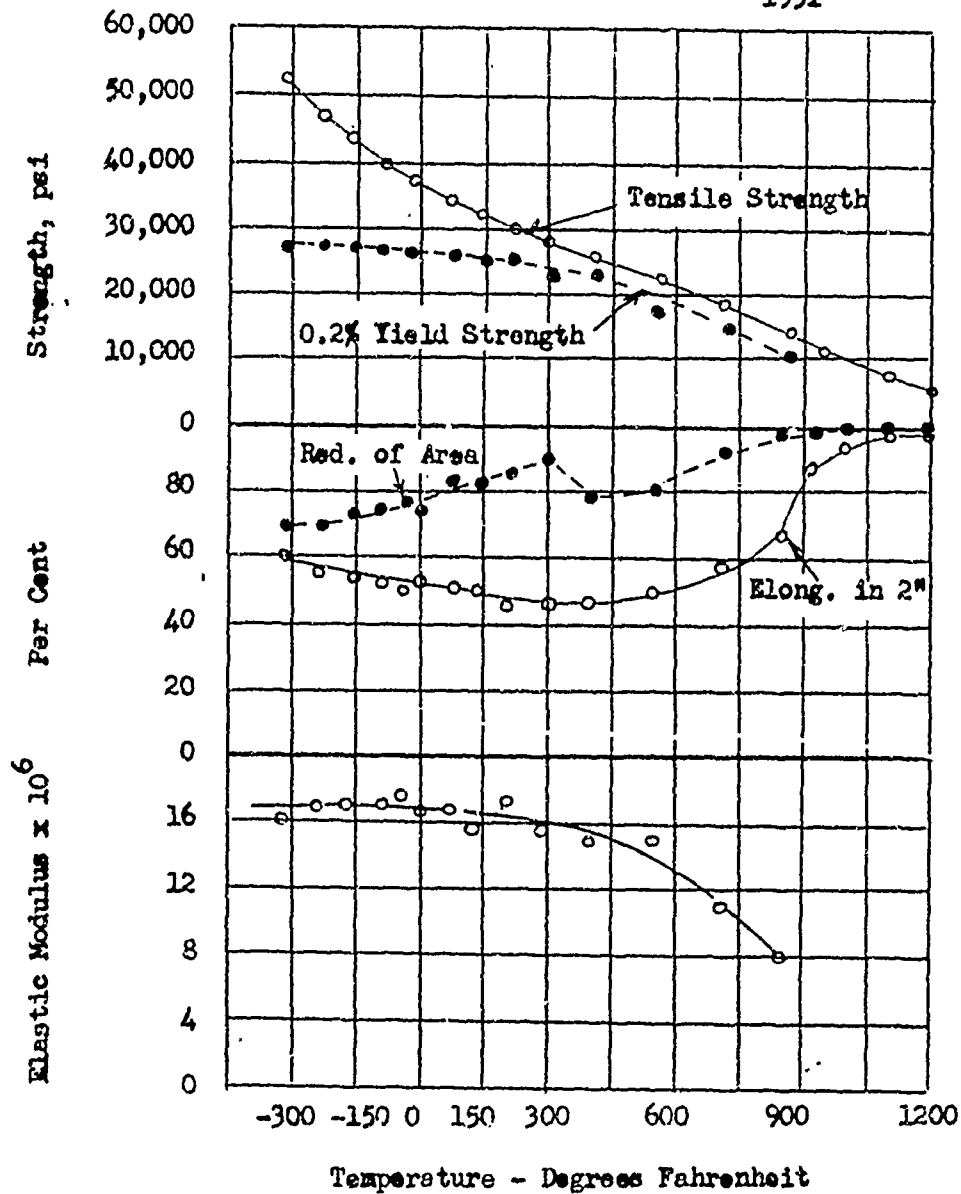


Young's modulus vs. temperature of phosphor bronze, hard.

FIGURE 62

LOW TEMPERATURE MECHANICAL PROPERTIES OF COLD-ROLLED, DEOXIDIZED, HIGH-PHOSPHORUS COPPER

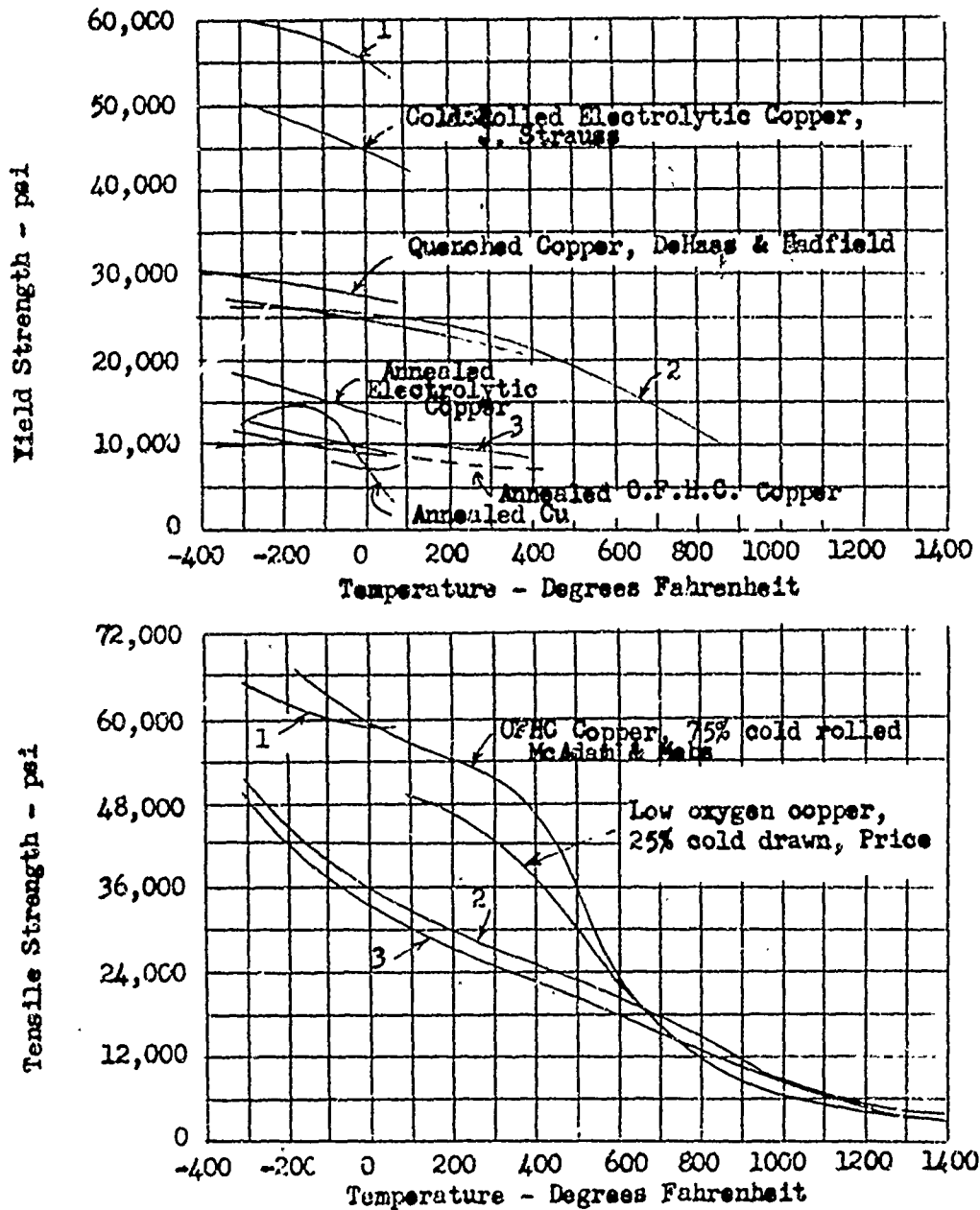
Data from Munse  
 & Weil, ASTM, Vol 51,  
 1951



Cold rolled - 5 to 7%

Figure 63

# YIELD AND TENSILE STRENGTHS OF VARIOUS COPPERS

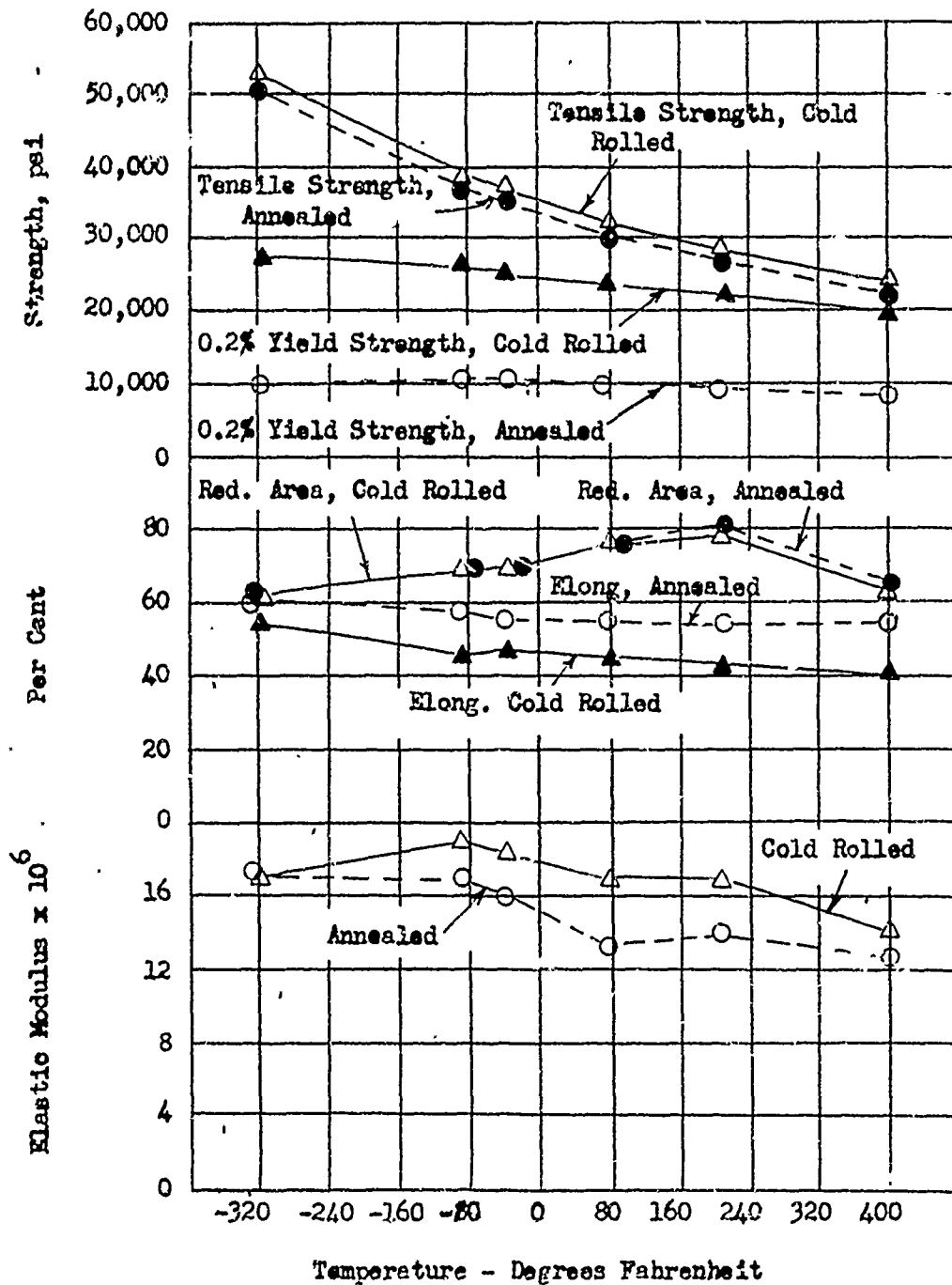


- 1 - Commercially cold rolled, Krupkowski, Broniewski, & Wesolowski.
- 2 - Deoxidized Copper, cold rolled 5-7%, U. of I. tests.
- 3 - Annealed Copper, U. of I. tests.

Data from Munse & Weil,  
 ASTM, Vol 51, 1951

Figure 64

# EFFECT OF TEMPER UPON MECHANICAL PROPERTIES OF COPPER AT LOW TEMPERATURES



Cold rolled - 5 to 7%  
 Annealed - 1150°F for 1/2 hour

Data from Monse & Weil  
 ASTM, Vol 51, 1951

Figure 65

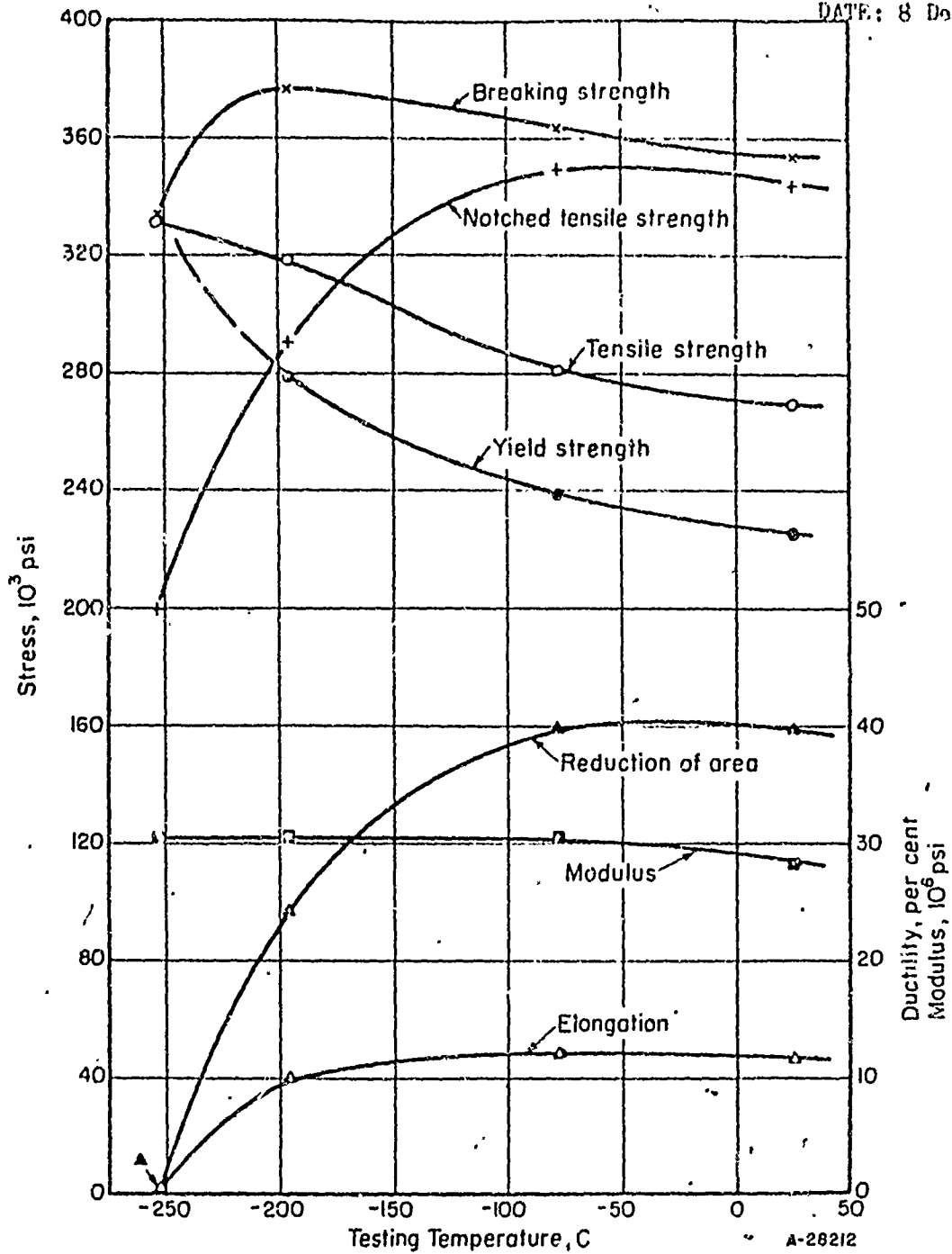


FIGURE 66 MECHANICAL PROPERTIES OF AISI 4340 STEEL  
 HEAT TREATED TO A 269,000-PSI TENSILE  
 STRENGTH - DATA FROM NAC REPORT 58-386.

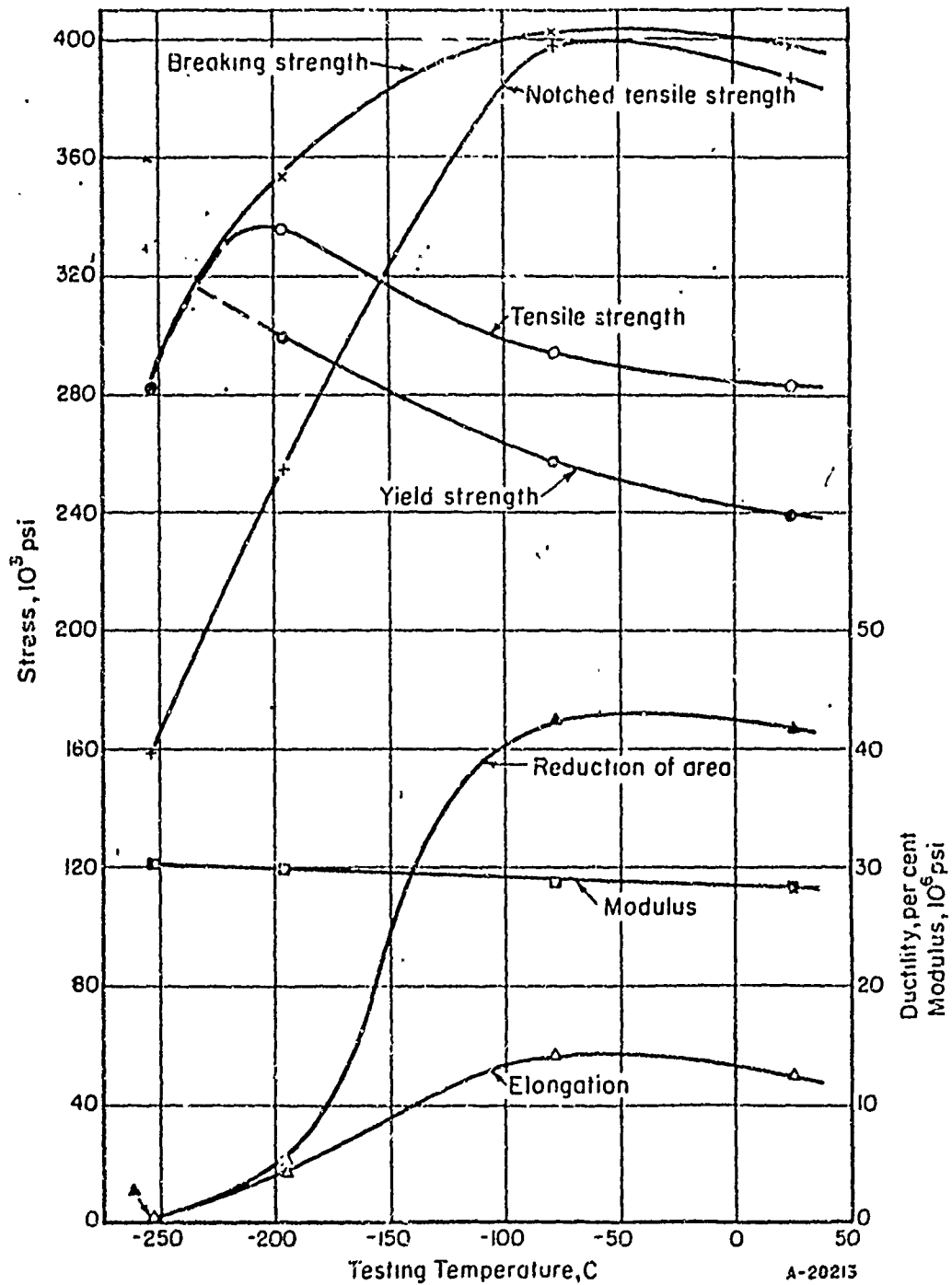
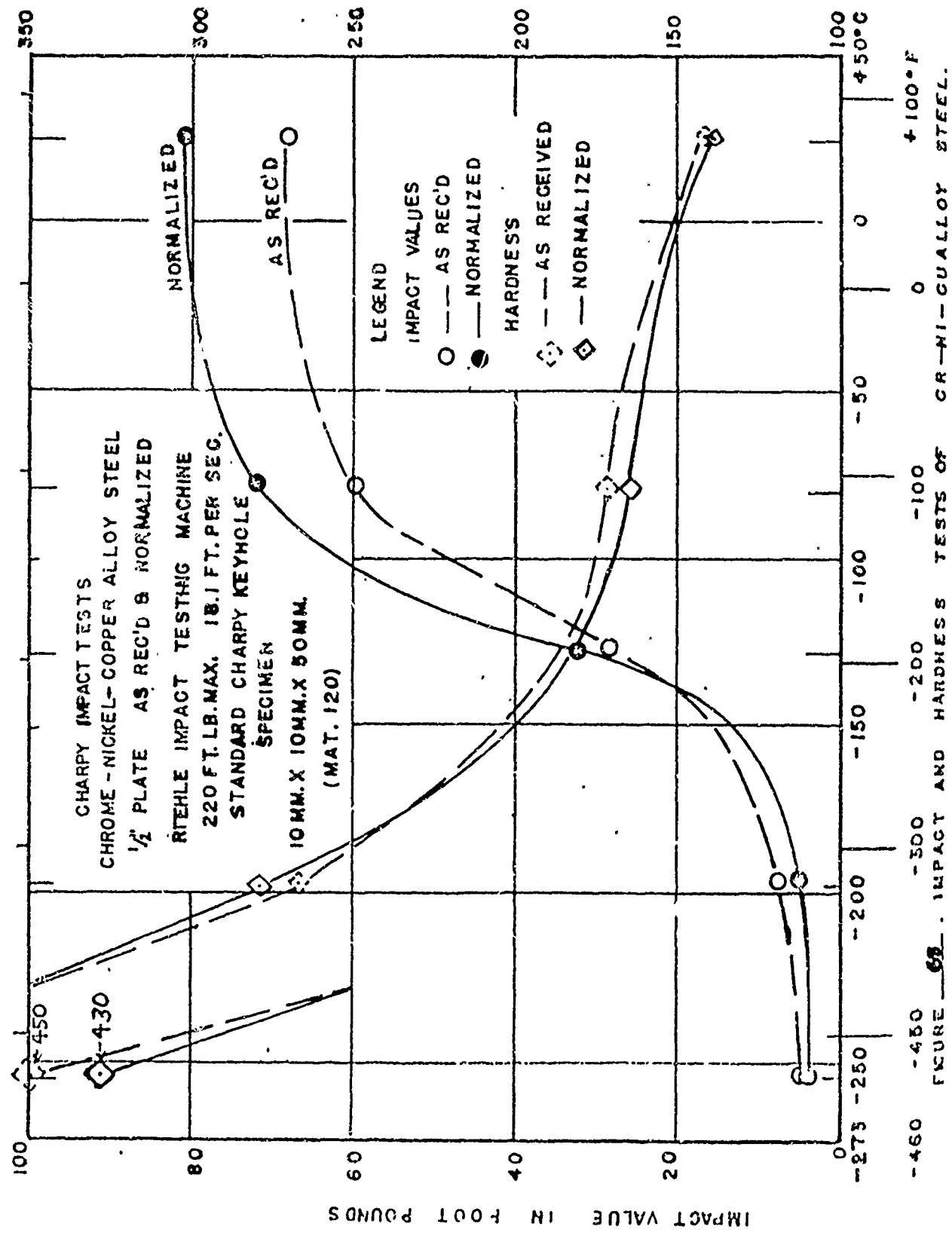


FIGURE 67 MECHANICAL PROPERTIES OF TRICENT STEEL HEAT TREATED TO A 283,000-PSI TENSILE STRENGTH  
 DATA FROM WADC REPORT 58-386.

# HARDNESS IN VICKERS PYRAMID NUMBERS



DATA FROM WADC REPORT 5662, Part 5.

HARDNESS IN VICKERS PYRAMID NUMBERS

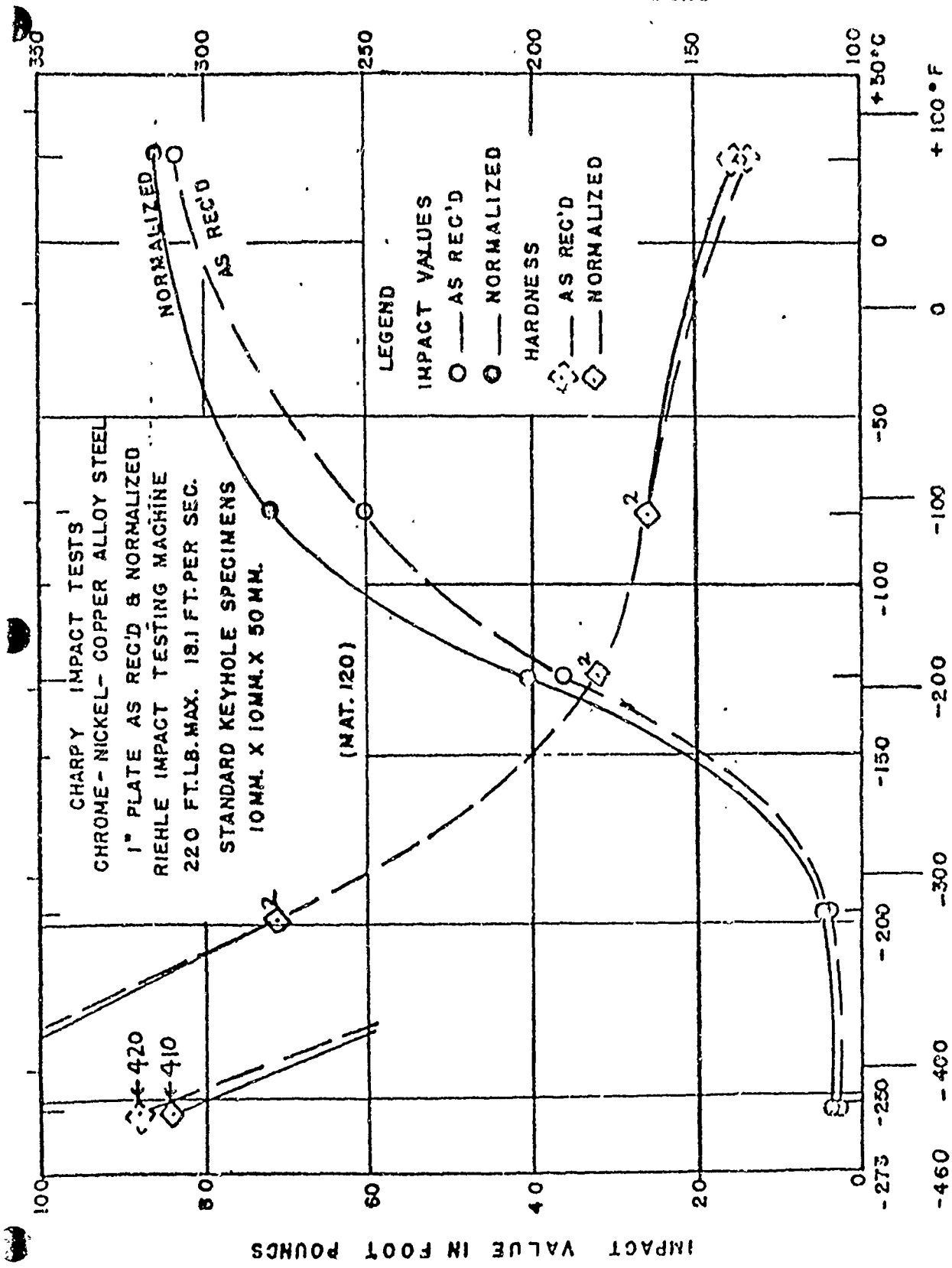


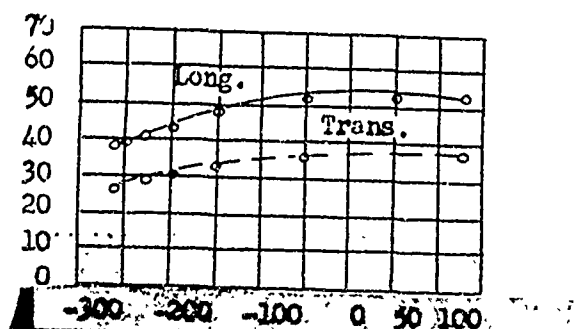
FIGURE 69 | IMPACT AND HARDNESS TESTS OF CR-NI-CU ALLOY STEEL

DATA FROM WADC REPORT 5662, Part 5

FIGURE 70

IMPACT PROPERTIES OF ALLOY STEELS  
 AT LOW TEMPERATURES

Keyhole Charpy  
 impact energy - ft. lb.

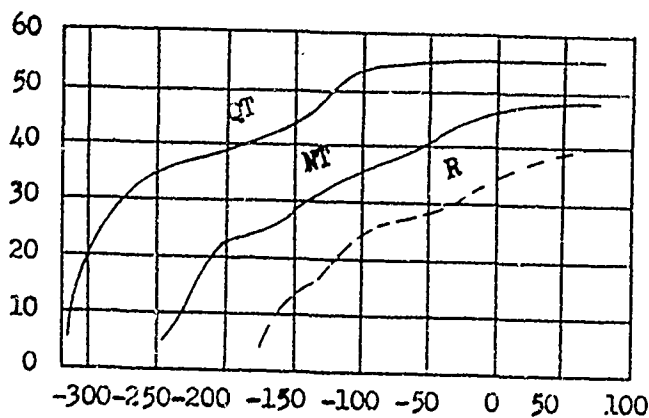


Temperature - Degrees Fahrenheit

Normalized and tempered 2810 Steel plate,  
 1/2" thick

EFFECT OF HEAT TREATMENT UPON IMPACT  
 PROPERTIES OF LOW ALLOY STEEL AT  
 AT LOW TEMPERATURES

Keyhole Charpy impact  
 energy - ft. lb.



Temperature - Degrees Fahrenheit

2317 Steel plate - 1/2" thick

QT- Quenched from 1525°F, tempered 1100°F.

NT- Normalized at 1600°F, tempered 1100°F.

R- As hot rolled

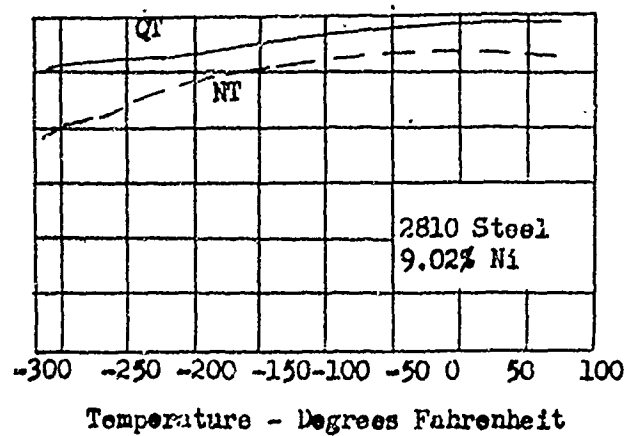
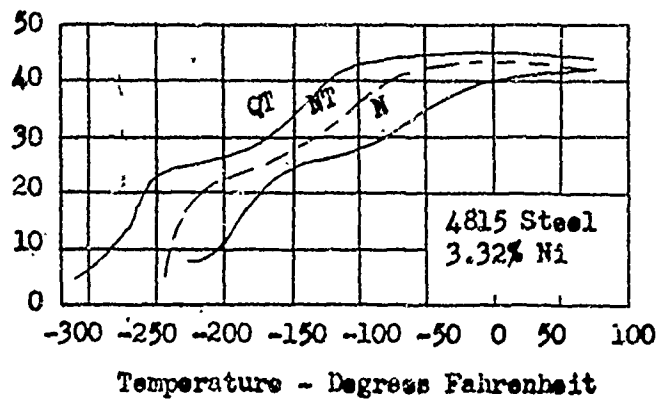
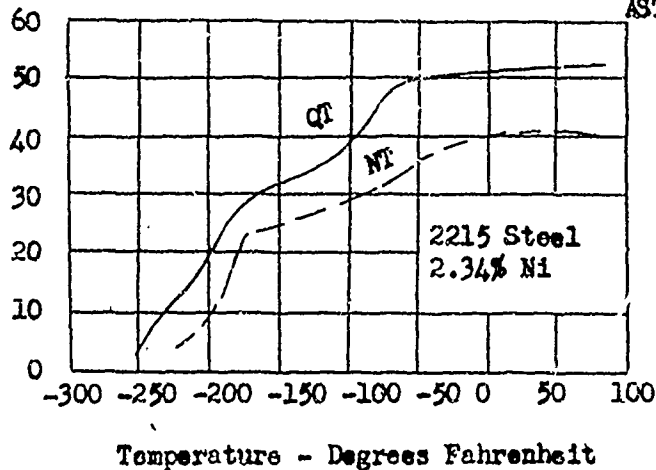
Data from Seens, Jensen & Miller  
 ASTM, Vol 51, 1951

Figure 71

EFFECT OF HEAT TREATMENT AND NICKEL  
 CONTENT ON IMPACT PROPERTIES OF LOW  
 CARBON ALLOY STEELS

Data from Seare,  
 Jensen, & Miller  
 ASTM, Vol 51, 1951

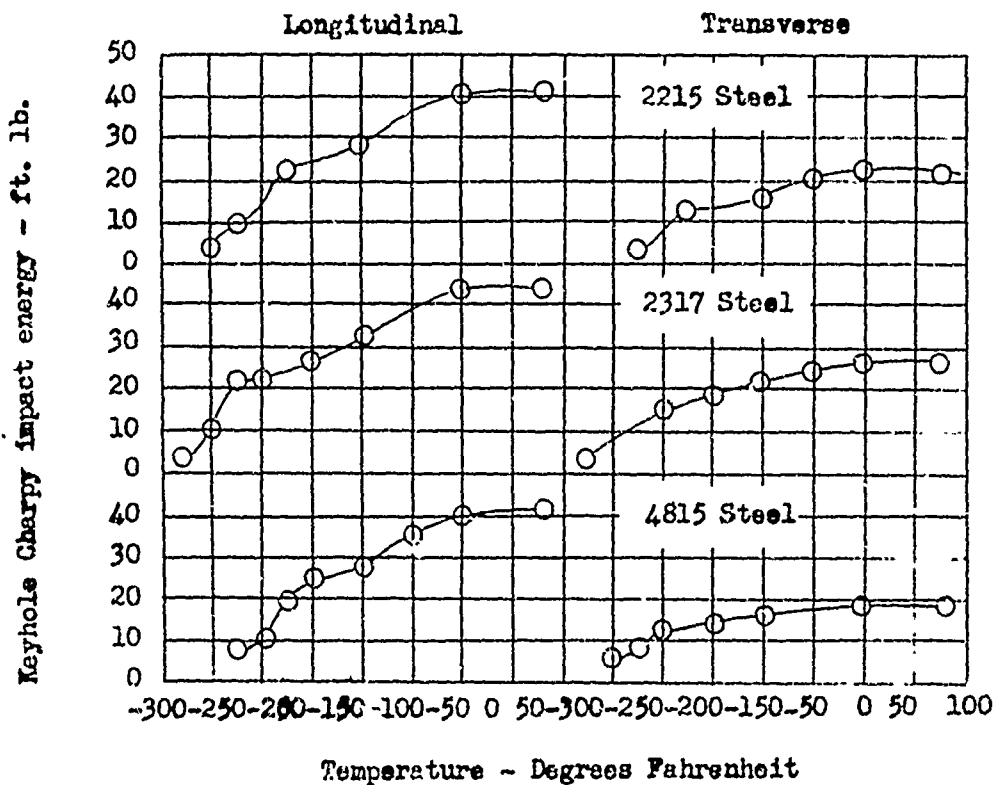
Keyhole Charpy Impact Energy - ft. lb.



- QT - Water quenched from 1450° or 1525°F,  
 Tempered 1050° or 1100°F
- NT - Normalized at 1600° or 1650°F,  
 Tempered at 1050° or 1100°F
- N - Normalized at 1600°F

FIGURE 72

IMPACT PROPERTIES OF NORMALIZED LOW ALLOY STEELS  
 AT LOW TEMPERATURES



Normalized 1/2" thick plates, Keyhole Charpy impact specimens taken longitudinal and transverse to rolling directions. Steels normalized at 1600°F, air cooled.

Data from Seens, Jensen & Miller  
 ASTM, Vol 51, 1951.

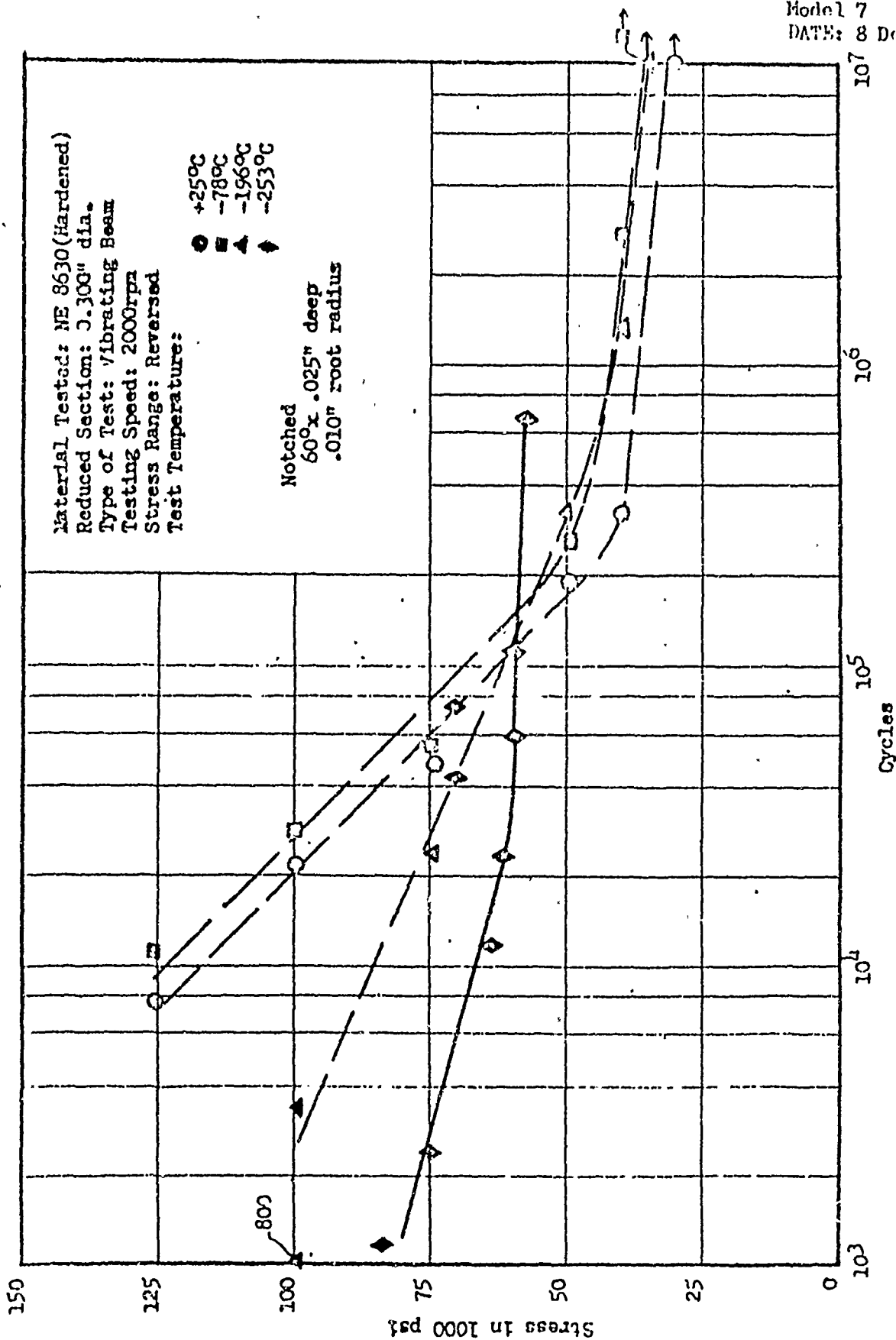
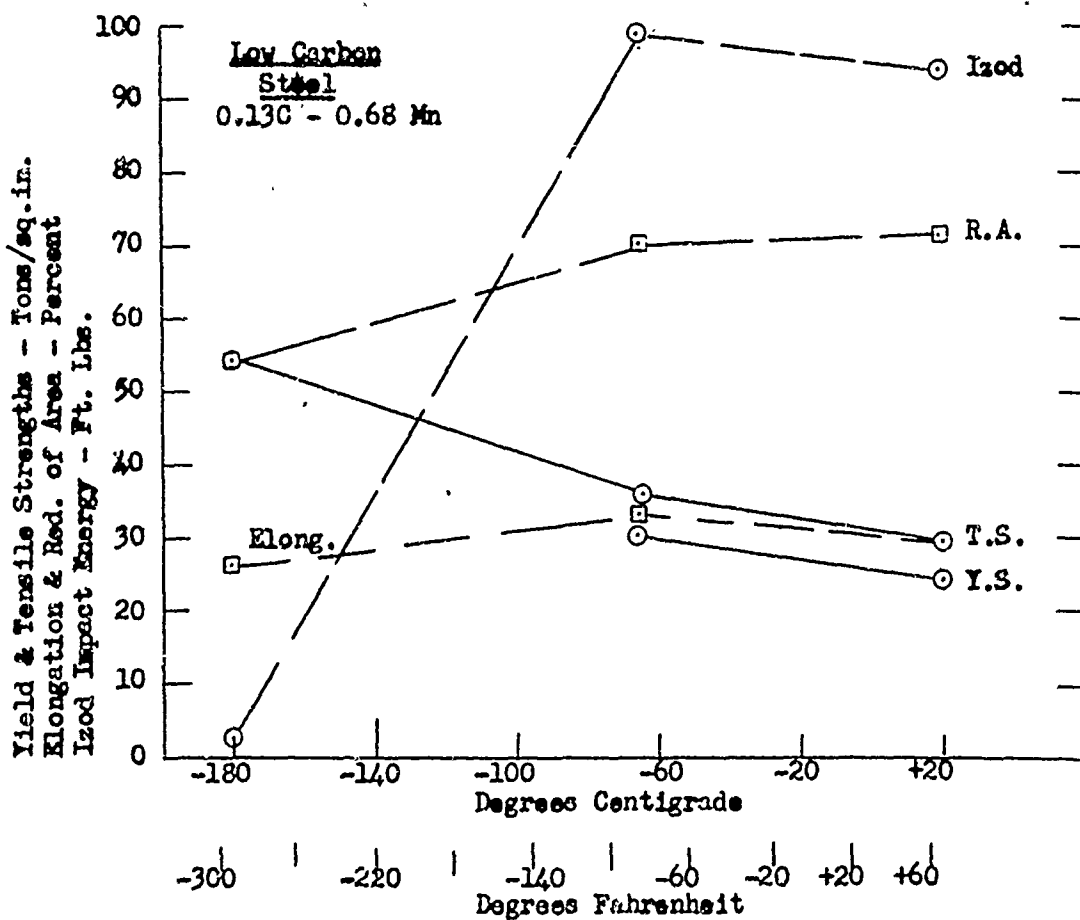
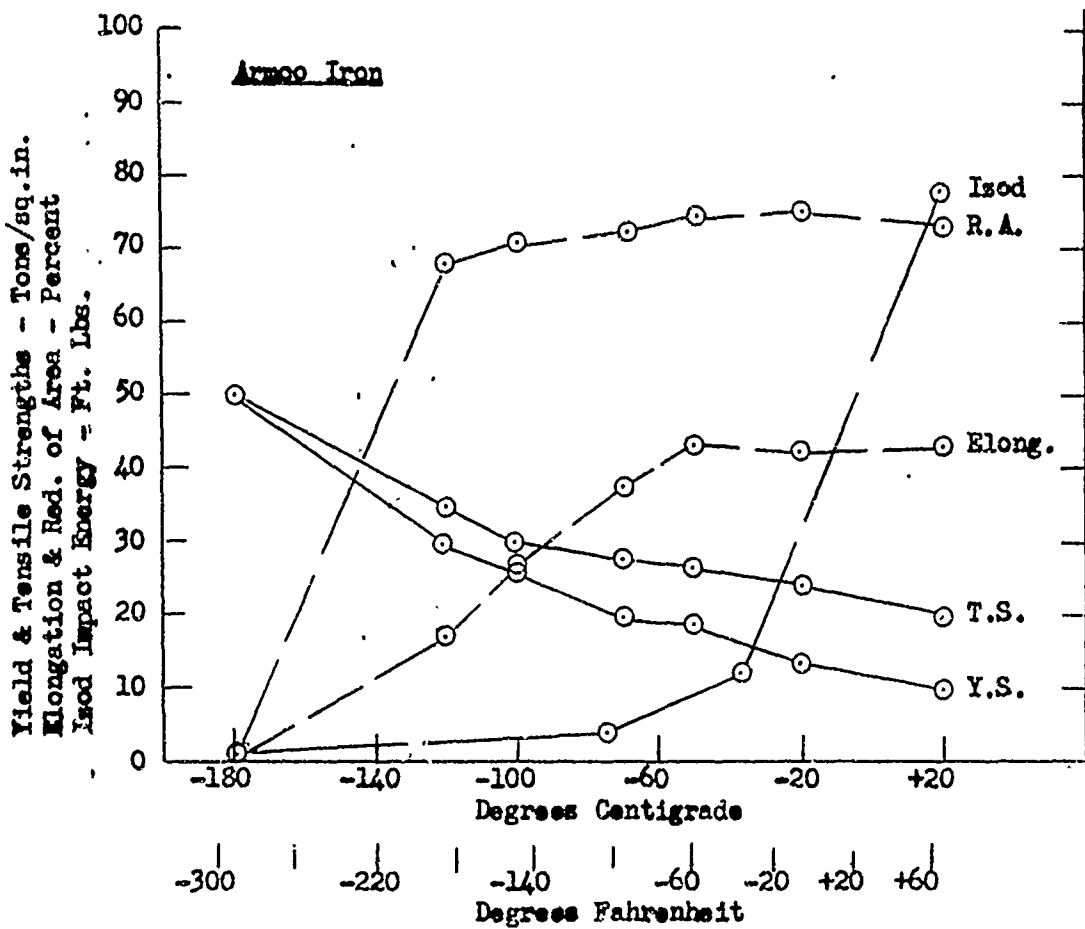


Figure 73. Results of Vibrating Beam Tests of Notched NE 8630 (Hardened) Specimens at -253°C (-423°F).  
 Curves for +25°C, -78°C, -196°C for comparison.  
 Data from WADC Report 5662, Part 5

FIGURE 7.  
MECHANICAL PROPERTIES OF IRON AND LOW CARBON STEEL AT LOW TEMPERATURES

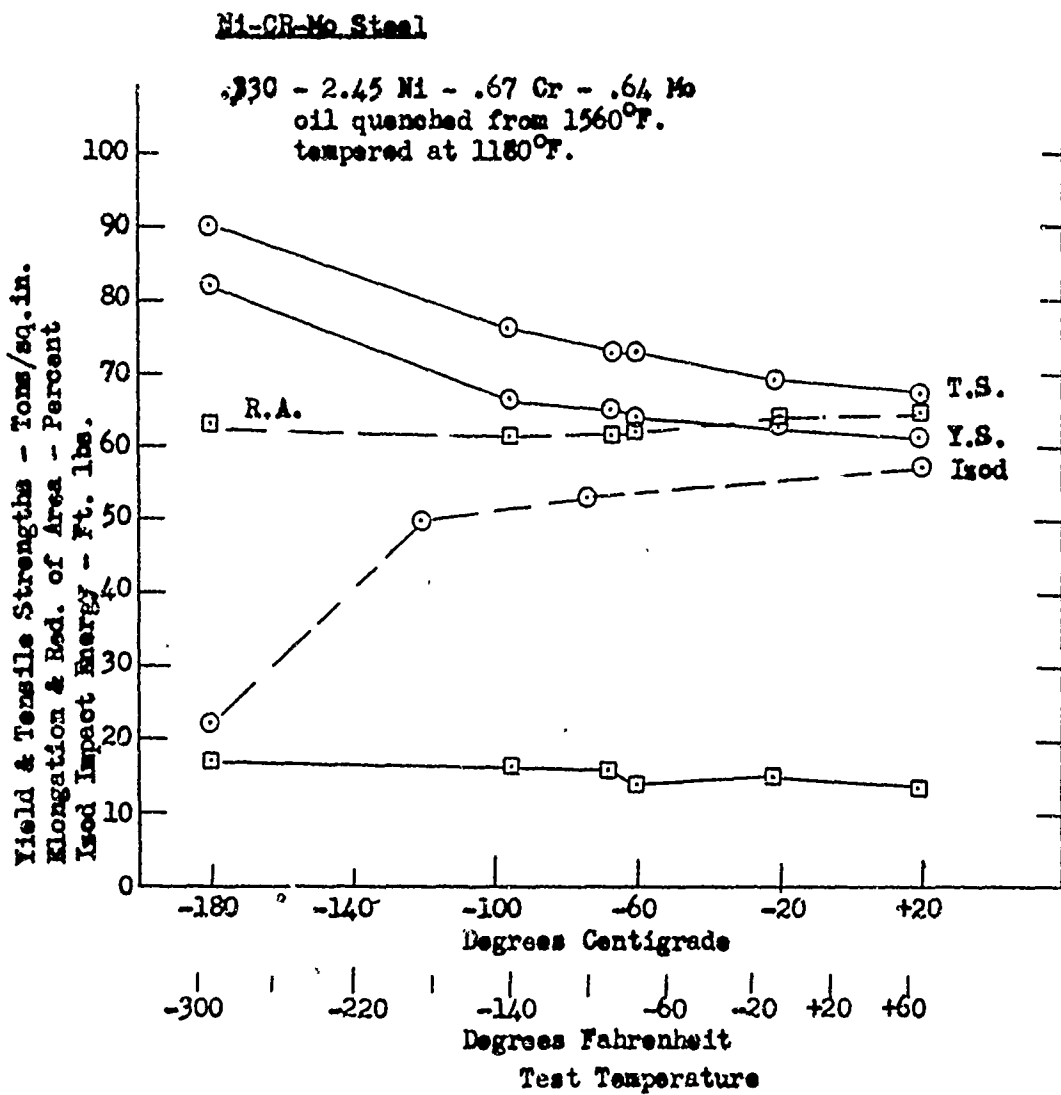
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Data from Colbeck, MacGillivray & Manning,  
Trans. Inst. Chem. Engr. 1933, Vol. 11.

FIGURE 75

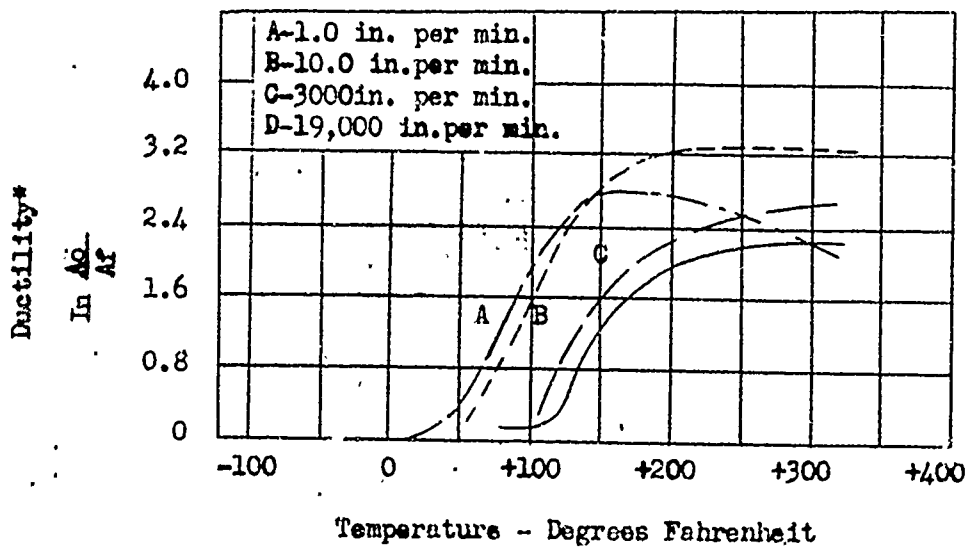
MECHANICAL PROPERTIES OF HEAT TREATED MEDIUM ALLOY STEEL  
 AT LOW TEMPERATURES



Data from Colbeck, MacGillivray  
 & Manning, Trans. Inst. Chem. Engr.  
 1933, Vol.11.

FIGURE 76

EFFECT OF STRAIN RATE ON DUCTILITY  
OF HIGH PURITY ZINC AT VARIOUS  
TEST TEMPERATURES



\*  $A_o$  - original cross-sectional area of tensile test specimen

$A_f$  - cross-sectional area at fracture

Data from Ripling & Baldwin  
ASTM, Vol 51, 1951

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FIG 17  
Part 7  
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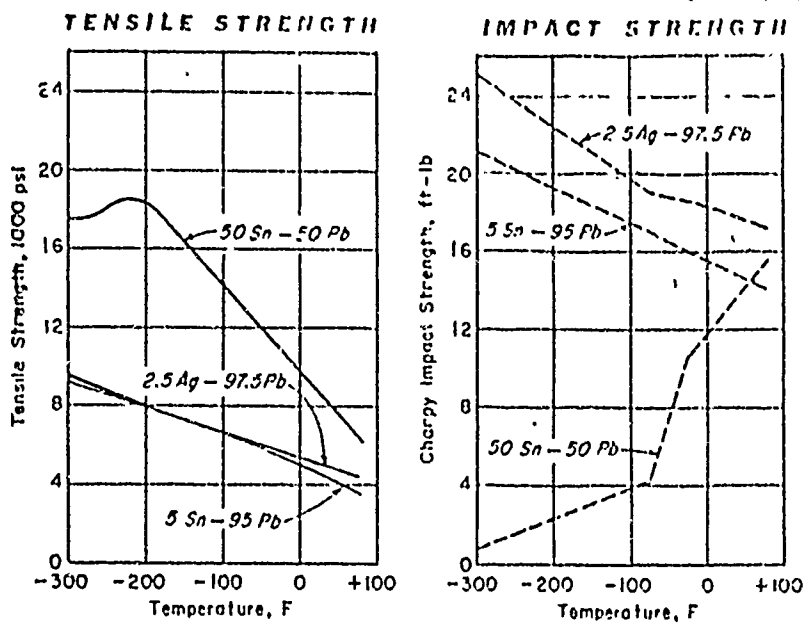


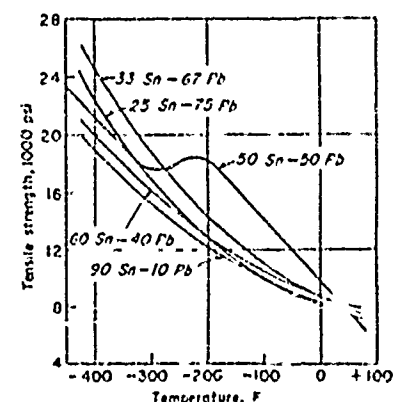
Fig 1—Tensile and impact strengths of lead-base solders are markedly influenced by composition.

HOW COLD AFFECTS STRENGTH OF SOME SOLDERS

Tradename	Nominal Composition, %	Tensile Strength, psi	
		80 F	-320 F
LEAD SOLDERS			
	Pb 95, Sn 5.....	3,500	9,200
	Pb 75, Sn 25.....	7,400	18,000
	Pb 67, Sn 33.....	7,600	26,000
	Pb 50, Sn 50.....	6,200	17,600
	Pb 97.5, Ag 2.5.....	4,500	9,600
	Pb 97.5, Ag 1.5, Sn 1.0.....	3,600	9,000
TIN SOLDERS			
	Sn 90, Pb 10.....	7,600	16,000
	Sn 60, Pb 40.....	8,000	17,000
Correcast	Sn 48, Pb 36, Bi 16.....	6,000	1,000
Claude Michael #275.....	Sn 45, Pb 32, Cd 18, Bi 5.....	8,750	7,975
	Sn 95, Sb 5.....	5,800	12,000
INDIUM SOLDERS* (compositions not available)			
Indalloy #1.....	In 50, Sn.....	1,050	6,125
Indalloy #2.....	In 80, Ag, Pb.....	2,050	6,250
Indalloy #3.....	In 90, Ag.....	2,050	5,100
Indalloy #5.....	In 25, Pb, Sn.....	5,100	12,250
Indalloy #7.....	In 50, Pb.....	3,050	4,075
Indalloy #10.....	In 25, Pb.....	4,100	7,150

\*Potentially used or potentially valuable for low temperature services.

Data from Materials & Methods.



Lead tin solders containing more than 50% lead are the strongest at low temperature.

TABLE II  
LOW TEMPERATURE TENSILE TEST DATA ON SOLDERS

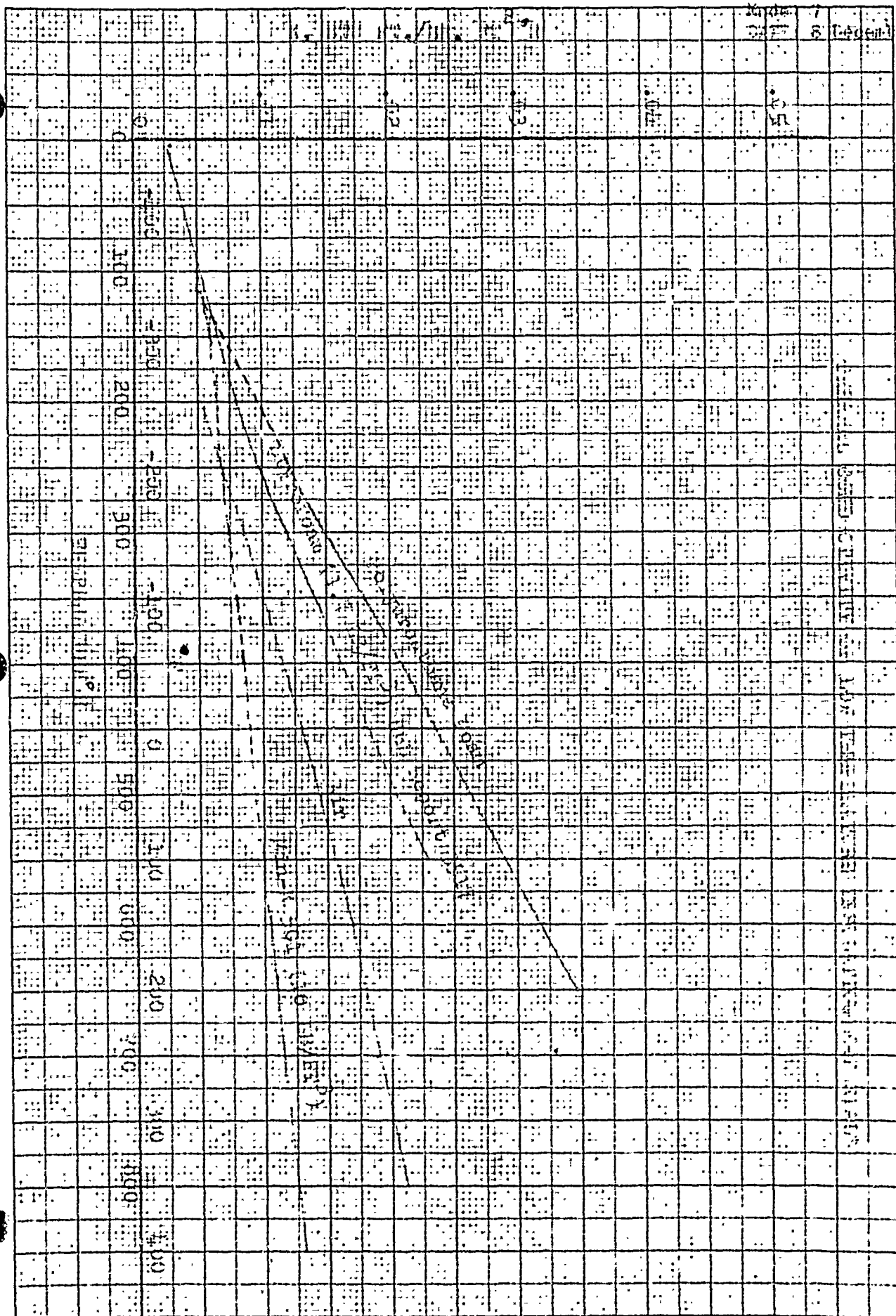
<u>Material</u>	<u>TENSILE STRENGTH, psi</u>			<u>REDUCTION OF AREA, %</u>		
	<u>+63°F</u>	<u>-321°F</u>	<u>-424°F</u>	<u>+63°F</u>	<u>-321°F</u>	<u>-424°F</u>
90Sn. 10Pb	7,700	16,000	20,000	*	18	2
60Sn. 40Pb	8,000	17,000	21,000	49	6	1
50Sn. 50Pb	7,700	20,000	26,000	66	3	6
33Sn. 67Pb	7,700	20,000	26,000	76	19	11
25Sn. 75Pb	7,400	18,000	24,000	87	27	21
45Ag. 30Cu. 25Zn	61,000	74,000	75,000	33	23	15
70Ag. 20Cu. 10Zn	34,000	54,000	57,000	15	21**	13

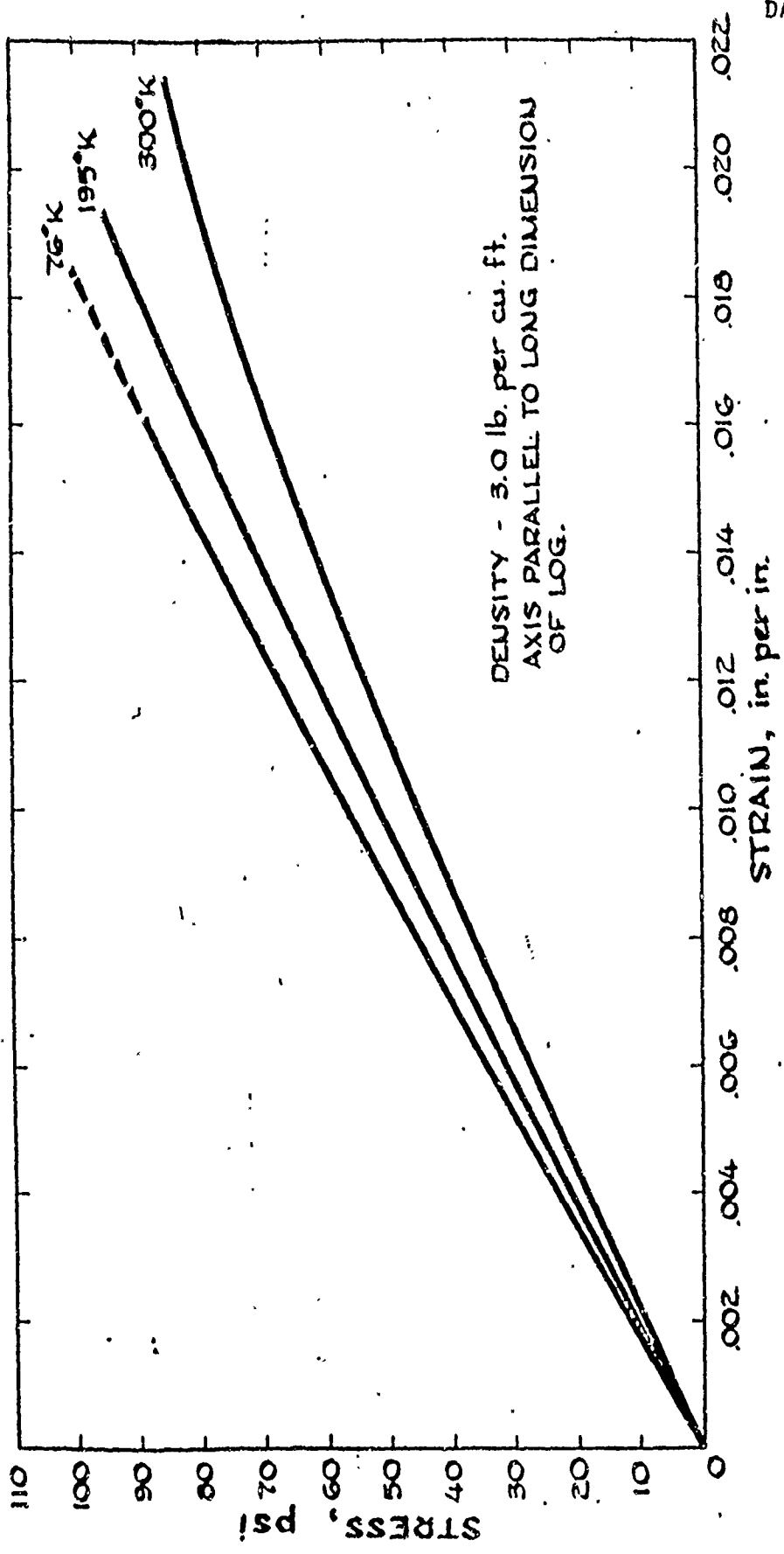
\* Wedge-shaped fracture.

\*\* The data showed a large spread.

Data from Kostenety & Ivanchenko.  
 Journal of Tech. Physics (U.S.S.R) 16, 1946.

10X10 TO TH 1/2 INCH 359-11  
KEUFFEL & ESSER CO

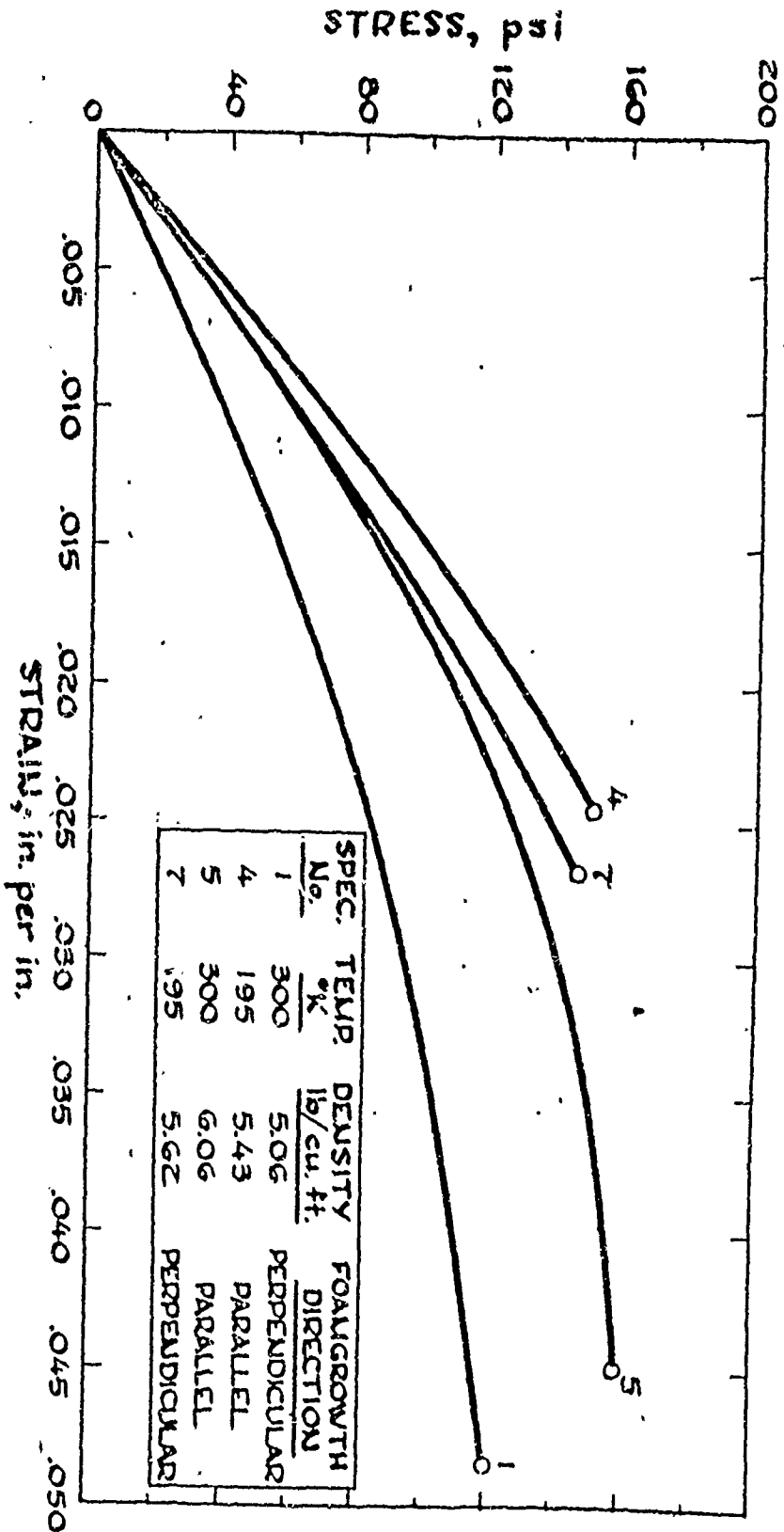




TYPICAL STRESS-STRAIN CURVES FOR EXPANDED POLYSTYRENE

FIGURE 78

DATA FROM NBS REPORT 5505, BY MCCLINTOCK,  
 VAN GURDY, AND KROPSCHOT



TYPICAL STRESS - STRAIN CURVES FOR EXPANDED EPOXY RESIN

FIGURE 79

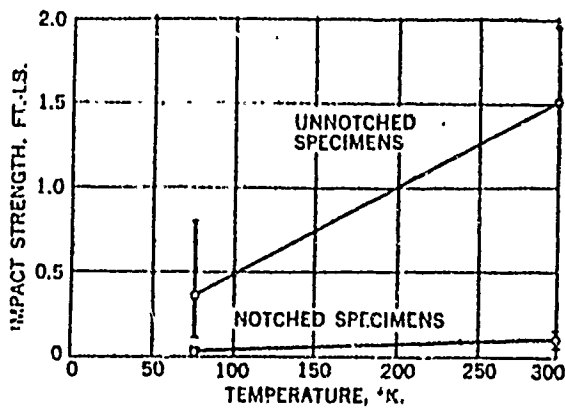


Fig. 2: Impact strength of a filled epoxy resin vs. temperature

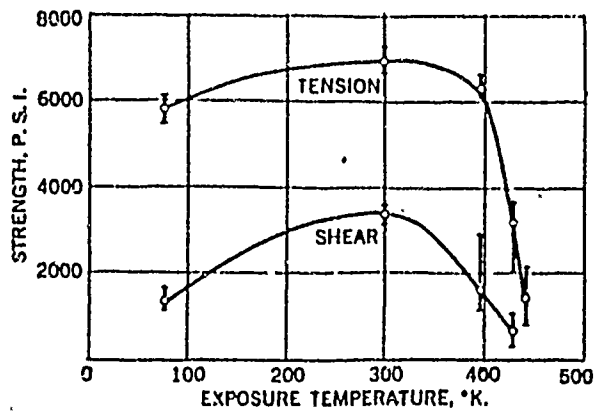
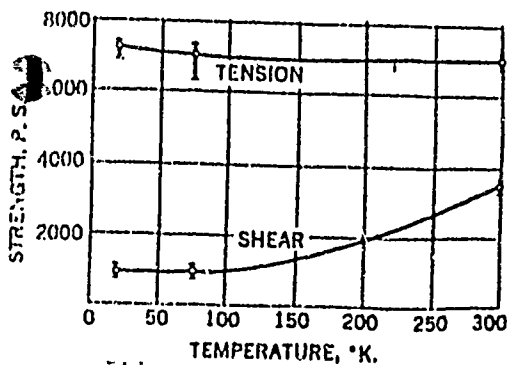


Fig. 3: Strength of filled epoxy adhesive bond vs. exposure temperature prior to testing at room temperature



Strength of a filled epoxy adhesive bond vs. temperature

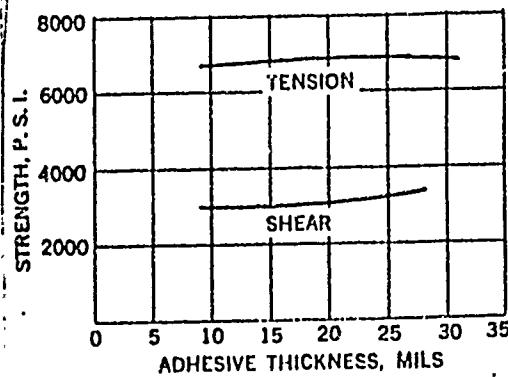


Fig. 6: Strength of a filled epoxy resin adhesive bond vs. thickness

FIGURE 80

DATE FROM NBS, R. M. McCLINTOCK

TABLE XII  
 ULTIMATE TENSILE AND FLEXURE STRENGTH OF FIBERGLASS LAMINATE  
 (TREVARNO F-92)

<u>Temperature °F</u>	<u>Ultimate Tensile Strength psi</u>	<u><math>E_B</math></u>	<u>Flexure Strength, psi</u>
70	30,900	$1.50 \times 10^6$	18,900
-100	43,600	$2.29 \times 10^6$	27,100
-320	52,600	$1.93 \times 10^6$	28,000

(Each number average of four tests on 1/8" x 1/4" x 2" samples)

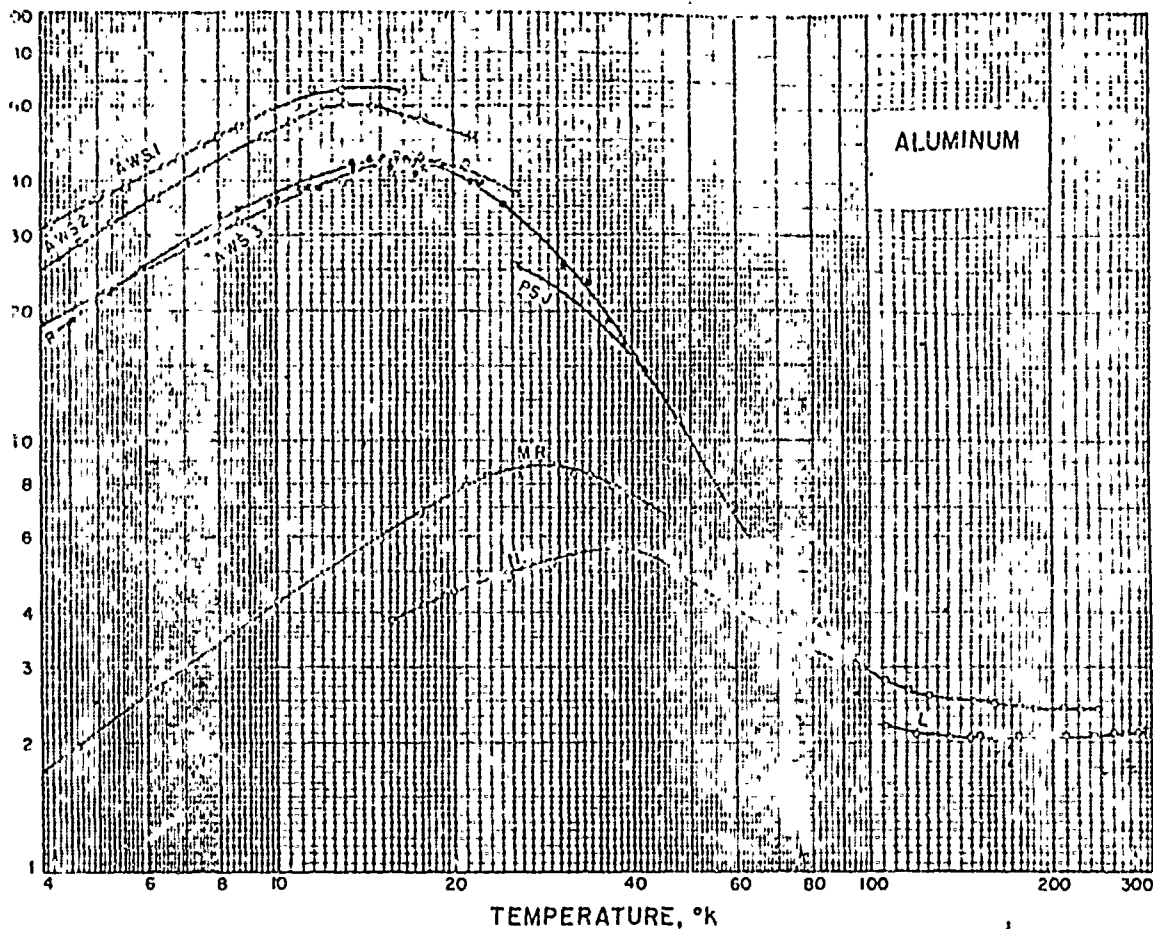
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UCRL-3421

### CONVERSION TABLES

Quantity	Multiply quantity expressed in	by	To obtain quantity expressed in
Viscosity	micropoise	$1 \times 10^{-6}$	$\frac{\text{g}}{\text{cm sec}}$
	micropoise	$6.73 \times 10^{-8}$	$\frac{\text{lb(m)}}{\text{ft sec}}$
Density	g/liter	$6.24 \times 10^{-2}$	lb/ft <sup>3</sup>
Heat Transfer	watts/cm <sup>2</sup>	927	watts/ft <sup>2</sup>
Sound Velocity	meters/sec	3.28	ft/sec
Thermal Conductivity	watts/cm °K	2.54	watts/in °K
		57.8	$\frac{\text{BTU ft}}{\text{ft}^2 \text{ hr } ^\circ\text{F}}$
Specific Heat	$\frac{\text{watts - sec}}{\text{g } ^\circ\text{K}}$	454	$\frac{\text{watts - sec}}{\text{lb } ^\circ\text{K}}$
		0.239	$\frac{\text{cal}}{\text{g } ^\circ\text{K}}$
		0.239	$\frac{\text{BTU}}{\text{lb } ^\circ\text{F}}$

FIGURE 82



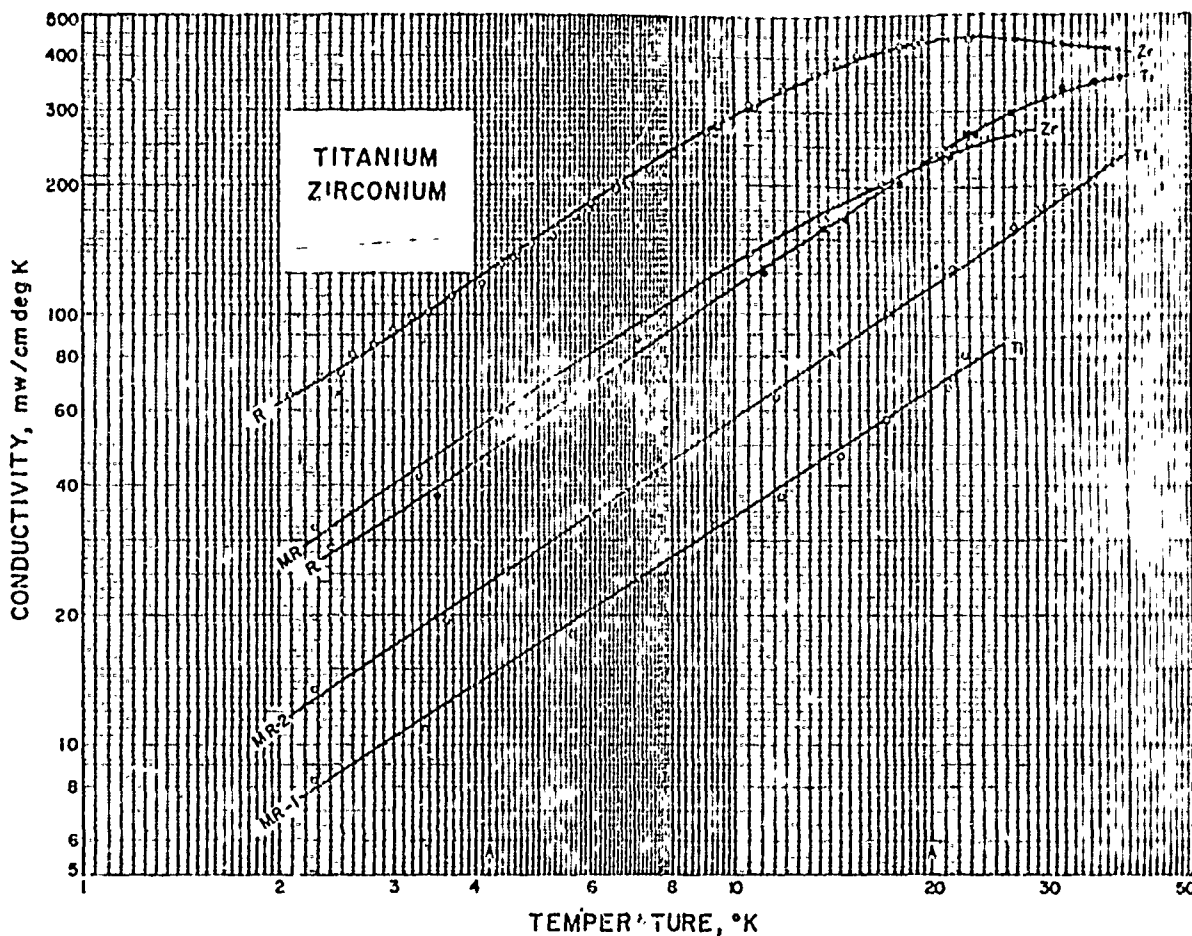
ALUMINUM

Curve	Sample source and analysis	Remarks	Reference
.....	"Pure" .....	Low value of $k=1.43$ at $0^\circ\text{C}$ ; R...	L. Lorenz (1881a).
.....	0.8% Fe, 0.4% Cu.	$k=2.01$ at $18^\circ\text{C}$ ; R, Cp.....	W. Jaeger and H. Dieselhorst (1900).
L.....	Johnson, Matthey; 99% pure.	Lathe turned from larger sample, density of 2.70.	C. H. Lee (1908).
.....	Commercial.....	$k=1.92$ at $0^\circ\text{C}$ , 1.90 at $85^\circ\text{K}$ , 1.89 at $21.4^\circ\text{K}$ .	R. Schott (1916).
.....		Measured the effect of torsion on the thermal and electrical conductivity.	J. E. Callirop (1926).
.....	8 samples ranging from pure to technical.	Measured at $20^\circ$ and $80^\circ\text{K}$ ; results for purest samples lie just below curve of P. B. J.; studied effect of grain size and crystal boundaries.	F. Grünisen and E. Gooss (1927); E. Grünisen (1927).
.....	"Pure".....	$k=2.26$ at $0^\circ\text{C}$ , 2.55 at $80^\circ\text{K}$ ; R...	J. Stachler (1929).
.....	do.....	$k=2.26$ at $0^\circ\text{C}$ , 2.56 at $80^\circ\text{K}$ ; also measured R.	W. Mannechen (1931).
.....	Approx. 99.7% pure; technically pure.	Two samples gave values at $0^\circ\text{C}$ of $k=2.26$ .	A. Eucken and H. Warrentrop (1935).
N .....	Hadfield's.....	Brinell hardness of 17.	J. de Nobel (1931).

ALUMINUM (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
A. W. B. 1	Alcoa; 99.998% pure, .001% Mg, .001% Fe, .0004% Cu, .004% Na.	Single crystal; residual electrical resistance of $1.19 \times 10^{-3}$ Rmm; $\alpha=2.7 \times 10^{-4}$ , $\beta=7.04$ .	R. A. Andrews, R. T. Webber, and D. A. Hopkr (1951).
A. W. B. 2	.....do.....	Single crystal, $R=1.48 \times 10^{-3}$ Rmm; $\alpha=2.72 \times 10^{-4}$ , $\beta=6.06$ .	Do.
A. W. B. 2.	Johnson, Matthey; 99.993% pure; .002% Mg, .001% Fe, .0008% Cu, trace of Na.	Polycrystalline rod; residual resistance of $2.14 \times 10^{-3}$ Rmm; $\alpha=2.72 \times 10^{-4}$ , $\beta=4.66$ .	Do.
P. B. J.....	Alcoa; 99.99% pure.	Cold-drawn.....	R. W. Powers, D. Schwartz, and H. L. Johnston (1951).
M. R.....	Johnson, Matthey; 99.994% pure.	Annealed polycrystal; $\alpha=2.2 \times 10^{-4}$ , $\beta=2.3$ .	K. Mendelssohn and H. M. Rosenberg (1952a).
.....		Polycrystalline; superconducting state; representative values were .07 at $0.8^\circ\text{K}$ , .015 at $0.85^\circ\text{K}$ , .007 at $0.37^\circ\text{K}$ .	K. Mendelssohn and C. A. Roston (1953).
R.....		$\alpha=2.2 \times 10^{-4}$ , $\beta=0.23$ .....	H. M. Rosenberg (1951a).

FIGURE 83 - DATA FROM NBS CIRCULAR NO. 556



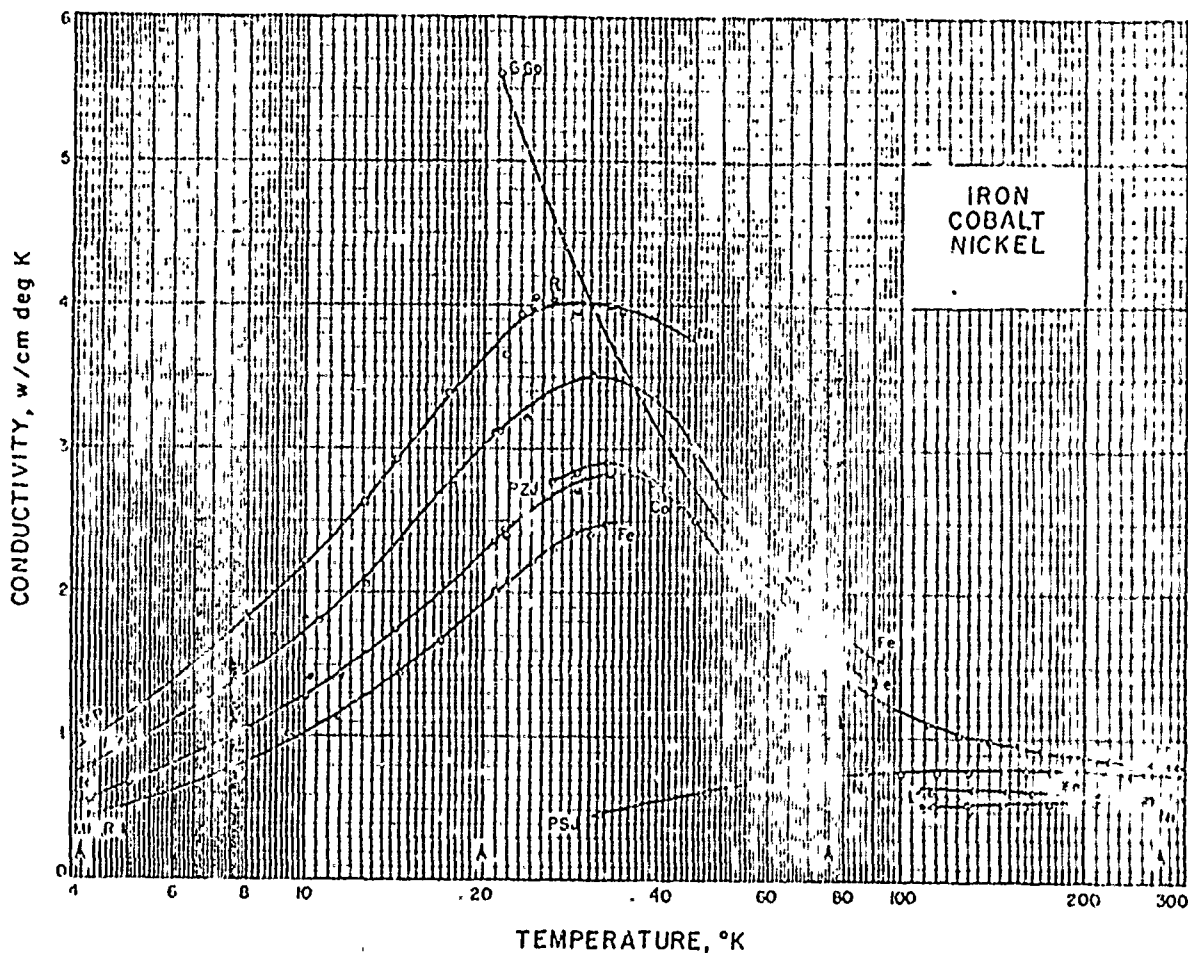
TITANIUM			
Curve	Sample source and analysis	Remarks	Reference
.....	Comma, pure	Abstract only, $k=0.20$ at $273^\circ\text{K}$ , $0.31$ at $196^\circ\text{K}$ , $0.18$ at $90^\circ\text{K}$ , $0.12$ at $20^\circ\text{K}$ .	C. J. Rigby and L. I. Boettcher (1951).
M. R. 1...	Amco Elect Ind. Hon. Lab. England; 99.9% pure.	Unannealed; $\beta=290$ .....	K. Mendelsohn and H. M. Rosenberg (1952b).
M. R. 2...	Same source; 99.99% pure.	Annealed; $\beta=179$ .....	Do.
R.....	.....	Single crystal; conductivity constant from $50^\circ$ to $100^\circ\text{K}$ ; $\alpha=464 \times 10^{-5}$ , $\beta=82$ .	H. M. Rosenberg (1954a).

ZIRCONIUM			
Curve	Sample source and analysis	Remarks	Reference
M. R. ....	Johnson, Matthey; 99.8% pure.	Annealed; $\alpha=120 \times 10^{-5}$ , $\beta=78$ .	K. Mendelsohn and H. M. Rosenberg (1952b).
R.....	.....	$\alpha=125 \times 10^{-5}$ , $\beta=24$ .....	H. M. Rosenberg (1954a).

Data from NBS Circular No. 556.

FIGURE 84

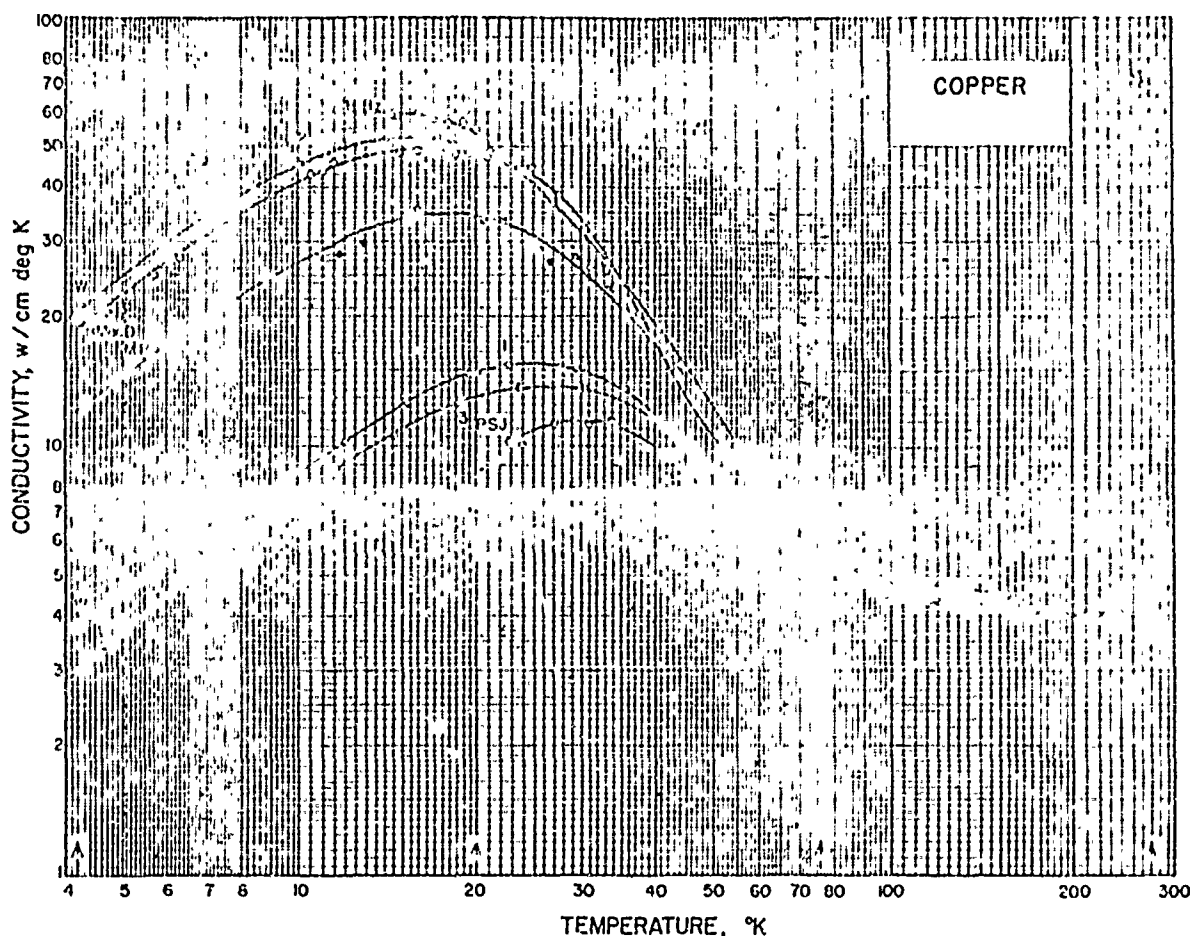
FIGURE 85



IRON				IRON (Cont'd)			
Curve	Sample source and analysis	Remarks	Reference	Curve	Sample source and analysis	Remarks	Reference
.....	"Pure" .....	$k=0.70$ at $0^{\circ}\text{C}$ .....	L. Lorenz (1881a).	.....	"Technically pure".	Two samples untempered; electrolytic; $k=1.36$ and $0.91$ at $83^{\circ}\text{K}$ , $3.01$ and $0.5$ at $21^{\circ}\text{K}$ .	E. Grüneisen and E. Goens (1927).
.....	"Pure", .1% C, .06% Mn, .02% Ni, .03% Cu, .03% P, .03% S, .02% B.	$k=0.72$ at $18^{\circ}\text{C}$ .	E. Grüneisen (1900).	.....	"Pure" .....	Electrolytic; $k=0.77$ at $18^{\circ}\text{C}$ .....	R. Kikuchi (1932).
.....	0.1% C+metals	Also measured R, Cp, emf; $k=0.67$ at $18^{\circ}\text{C}$ .	W. Jaeger and H. Dinschke (1900).	.....	Armco; .01% C, .02% Mn, .008% P, .026% S, .06% Ca, .02% Si.	$k=0.7$ at $0^{\circ}\text{C}$ , $0.72$ at $195^{\circ}\text{K}$ , $0.94$ at $90^{\circ}\text{K}$	W. G. Kannaluk (1933).
.....	Krupps; .1% C, .2% Si, .1% Mn.	Also measured R, Cp, emf; $k=0.60$ at $18^{\circ}\text{C}$ .	Do.	.....	"Pure" .....	Between $3^{\circ}$ and $20^{\circ}\text{K}$ , the values fall just below the curve marked M. R.	J. Karwajl and K. Schäfer (1939).
.....	99.42% pure; .1% C, .15% Mn, .13% Si.	Wrought iron.....	C. H. Lee (1903).	.....	Hadfield; 99.94% pure.	Forged; $k=0.9$ at $90^{\circ}\text{K}$ , maximum of $1.2$ at $82^{\circ}\text{K}$ , $0.5$ at $15^{\circ}\text{K}$ .	J. de Nobel (1921).
.....	.....	Electrolytic; two rolls with average grain size of $1 \times 10^{-3}$ and $5 \times 10^{-4}$ cm; $k=0.94$ and $0.9$ , respectively, at $0^{\circ}\text{C}$ ; $k=1.81$ and $1.63$ at $60^{\circ}\text{K}$ .	A. Eucken and K. Dietrich (1927).	P. Z. J. ....	Johnson, Matthey; 99.99% pure.	.....	R. W. Powers, J. H. Ziegler, and H. L. Johnson (1931a).
.....	Heraeus .....	Electrolytic; average grain size $2 \times 10^{-3}$ cm; $k=0.82$ at $0^{\circ}\text{C}$ and $1.17$ at $60^{\circ}\text{K}$ .	Do.	M. R. ....	Johnson, Matthey; 99.99% pure.	$\alpha=18 \times 10^{-4}$ , $\beta=9.5$ .....	K. Mendelsohn and H. M. Rosenberg (1922b).
0 (Go. ....	"Double rolled, annealed."	Tempered; electrolytic.....	E. Grüneisen and E. Goens (1927).	R. ....	.....	$\alpha=103 \times 10^{-4}$ , $\beta=9.1$ .....	H. M. Rosenberg (1924a).

Data from NES Circular No. 556

FIGURE 25



COPPER

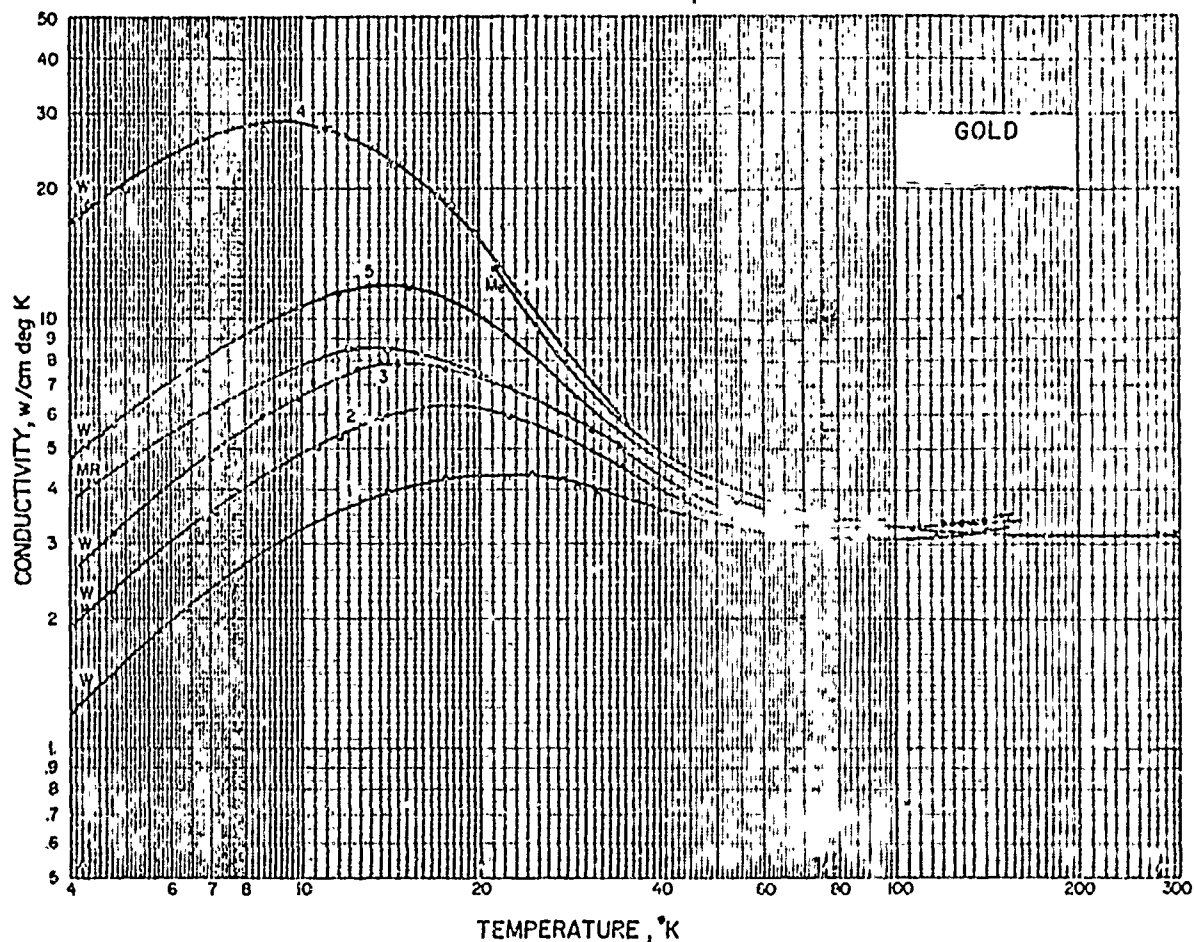
Curve	Sample source and analysis	Remarks	Reference
.....	"Pure".....	$k=3$ at 0°C .....	L. Lorenz (1881a).
.....	.....	One sample had $k=3.6$ at 10°C; the second, 1.3 at 10°C.	J. H. Gray (1895).
.....	"Pure".....	$k=3.9$ at 18°C.....	K. Grünisen (1900).
.....	do.....	$k=3.73$ at 18°C; R, Cp.....	W. Jaeger and H. Henschelhorst (1900).
.....	do.....	$k=3.85$ at 20°C.....	W. Schaufelberger (1902).
.....	.....	"Soft drawn, high conductivity"; $k=3.8$ at 27°C; results at 10°C are close to the P.S.J. curve.	G. H. Lee (1908).
.....	.....	Electrolytic copper wires. values at 21°, 91° and 273° are close to the W-1 curve.	W. Meissner (1915).
.....	"Very pure".....	Natural single crystal; results uncertain due to very small size of sample.	R. Schott (1916).
.....	"Tech. pure".....	Approximate on curve of W-3 down to 22°K.	DJ

COPPER (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
.....	.....	Measured 18 samples of various crystal structure, purity, and annealing at 21° and 83°K; R.	E. Grünisen and E. Lorenz (1927).
.....	Gen. Elec. ....	Single crystal; between 65° and 300°K, the results are close to curve W-1.	W. G. Kannaluk and T. H. Laby (1928).
.....	.....	Measured 14 different copper samples at 20° and 90°K; R.	E. Grünisen and H. Henschelhorst (1930).
H. Ba.	.....	.....	W. J. d. Haas and T. Henschelhorst (1935).
.....	.....	Studied effect of magnetic field on $k$ , R.	E. Grünisen and T. Adenstedt (1938).
Al Ma.	Johnson, Mat they; free of O; 0.03% each Ag, Ni, and Pb.	Machined and annealed .....	J. F. Allen and E. Mendosa (1947).
P.S.J.	Aus. Brass; "O. F. H. C."	Oxygen-free, high conductivity	R. W. Powers, D. Schwartz, and H. I. Johnston (1951).

Data from NBS Circular No. 556

FIGURE 87



GOLD

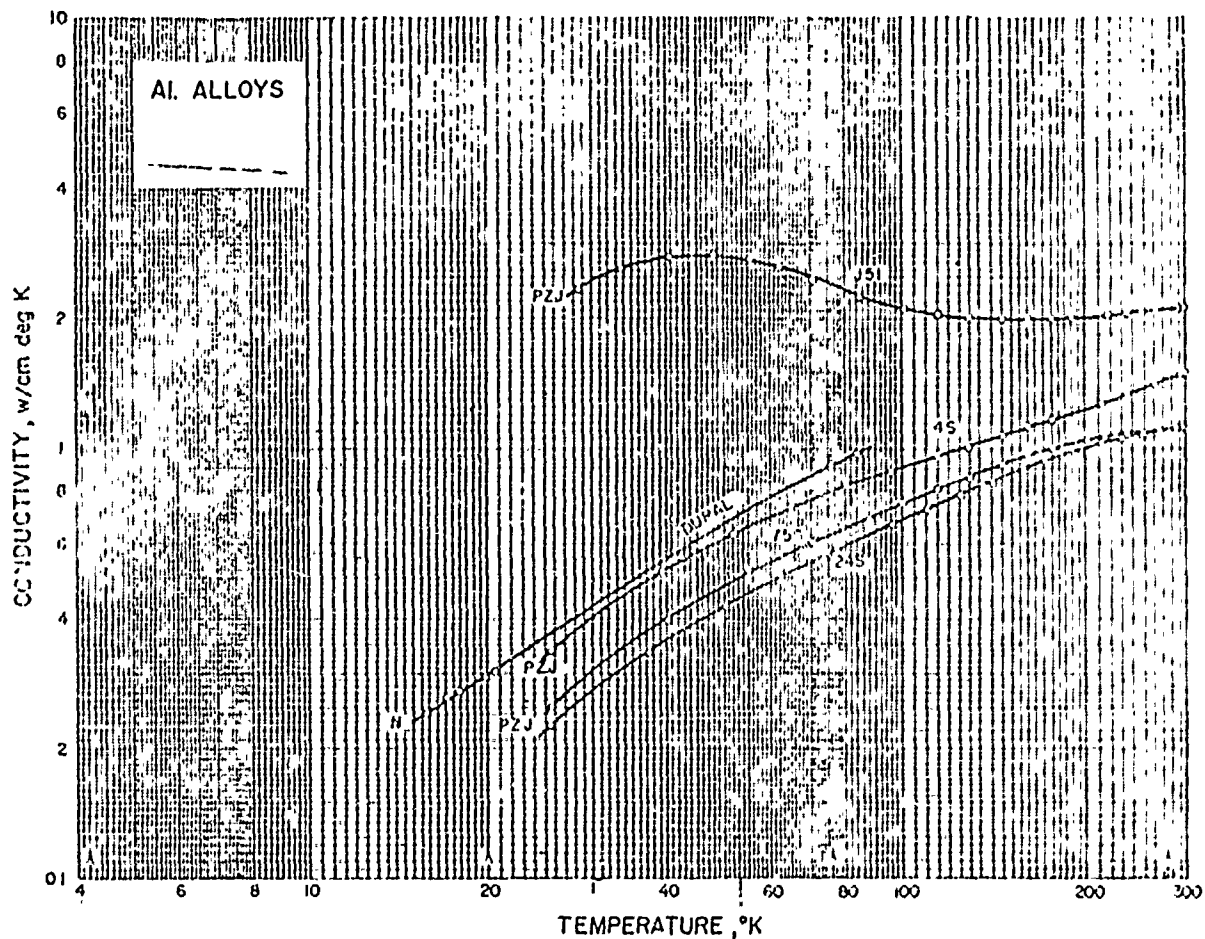
Curve	Sample source and analysis	Remarks	Reference
.....	.....	$k=3.14$ at $15^{\circ}\text{C}$ .....	J. H. Gray (1895).
.....	"Pure".....	$k=2.93$ at $18^{\circ}\text{C}$ ; a less pure sample had $k=1.79$ at $18^{\circ}\text{C}$ ; R, Cp, cmf.	W. Jacyer and H. Dracichoral (1900).
Mo.....	Mylius; 99.999% pure.	Cold-drawn; annealed.....	W. Meissner (1916).
.....	.....	$k=2.95$ at $17^{\circ}\text{C}$ .....	T. Barratt and R. M. Winter (1925).
.....	.....	$k=2.95$ at $24^{\circ}\text{C}$ .....	H. Mazumoto (1927).
.....	.....	Six samples of various composition, annealing; R Results for "very pure" gold at $21^{\circ}$ and $83^{\circ}\text{K}$ fall close to curve W.-4.	E. Grünisen and E. Goens (1927).
.....	.....	$k=3.04$ at $0^{\circ}\text{C}$ .....	W. G. Kaaschuk (1931).

GOLD (Cont'd)

Curve	Sample source and analysis	Remarks	Reference
M. R. ....	Johnson, Matthey; 99.999% pure.	$\alpha=18 \times 10^{-4}$ , $\beta=1.15$ .....	K. Mendelsohn and H. M. Rosenberg (1952a).
W. 1, 2.	Garrett, Davidson, Matthey, 99.9% pure (exam.); Ag, trace of Pt, Fe, Pb, Cu, Sn.	No. 1 sample unannealed; #2, annealed.	G. K. White (1953a).
W. 3, 4, 5.	Johnson, Matthey; 99.999% pure; trace of Ag, Cu; faint trace of Cd, Fe, Mg, Na, Ca, Zn.	No. 3 sample cold-drawn; #4, annealed in vacuum at $700^{\circ}\text{C}$ for 3 hours; #5 was the fourth re-drawn.	Do.
.....	.....	$\alpha=19 \times 10^{-4}$ , $\beta=1.13$ .....	H. M. Rosenberg (1953a).

Data from NBS Circular No. 556

FIGURE 88



ALUMINUM ALLOYS (Cont'd)

Nominal composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
8 Cu.....	k=1.32 at 273°K; 0.88 at 87°K...	W. Manneken (1931).
Do.....	k=1.31 at 273°K; 0.80 at 87°K...	Do.
18 Cu.....	k=1.18 at 273°K; .90 at 87°K....	Do.
8 Al.....	k=1.00 at 273°K; .73 at 87°K...	Do.
Do.....	k=1.05 at 273°K; .77 at 87°K; thermally treated.	Do.
12 Al.....	k=0.77 at 273°K; .56 at 87°K....	Do.
14 Mg.....	k=0.69 at 273°K; .44 at 87°K; thermally treated.	Do.
20 Si.....	k=1.39 at 273°K; 1.21 at 87°K; "Abaal".	Do.
4 Cu, 2 Ni, 1 S Mg; "Y" Alloy	k=1.62 at 273°K; 1.13 at 87°K...	Do.
Do.....	k=1.53 at 273°K; 1.38 at 87°K; thermally treated.	Do.
Mg, Mn, Sb; K-S Alloy 245	k=1.07 at 273°K; 1.00 at 87°K...	Do.
Mn, Mg, Sb; K-S Alloy 290	k=1.00 at 273°K; 0.80 at 87°K...	Do.
Mo, Mg, Sb; K-S Alloy Special	k=1.29 at 273°K; 1.14 at 87°K...	Do.
Cu, Mo, Mg, Nelson-Kullen 10	k=1.60 at 273°K; 1.22 at 87°K...	Do.
Cu; Nelson-Kullen Vn 1	k=1.43 at 273°K; 1.18 at 87°K...	Do.
Cu; Nelson-Kullen...	k=1.59 at 273°K; 1.30 at 87°K...	Do.
2-8 Cu, 0.5 Mg.....	k=1.00 at 273°K; 0.89 at 87°K...	Do.

ALUMINUM ALLOYS (Cont'd)

Curve	Composition (%)	Remarks	Reference
N.-"Dural"...	0.57 Mg, 0.47 Fe, 4.10 Cu, 94.0 Al.	As stamped; "Duraluminum".	J. de Nöel (1951).
P. Z. J.-J51...	0.29 Cu, 0.56 Mg, 0.02 Mn, 0.56 Fe, 0.39 Si, 0.01 Cr, 0.01 Ti.		H. W. Powers, J. H. Ziegler, and H. L. Johnston (1951).
P. Z. J.-4S...	0.10 Cu, 1.02 Mg, 1.20 Mn, 0.22 Fe, 0.13 Si, 0.02 Cr, 0.02 Ti.		Do.
P. Z. J.-788...	1.5 Cu, 5.6 Zn, 2.5 Mg, 0.1 Mn, 0.3 Cr.		Do.
P. Z. J.-243...	4.19 Cu, 0.01 Zn, 1.47 Mg, 0.66 Mn, 0.31 Fe, 0.13 Si, 0.01 Cr, 0.02 Ti.		Do.

Data from NBS Circular No. 556.

ALUMINUM ALLOYS (Cont'd)  
COMPANY AND TRADE MANUALS

ASTM designation	Trade designation	Nominal composition (%)	Conductivity	State
			w/cm deg K	
A2	EC 28; British BS 21	99.45 Al 99 Al	2.31 2.22 2.18	Annealed. H 18

WROUGHT ALLOYS

M1	38	1.2 Mn	1.93 1.83 1.59 1.55 1.63 1.63	O H 12 H 14 H 18 O H 38
	48	1.2 Mn, 1 Mg	1.63 1.63	O H 38
CP 21	118; British BS AL1	5.5 Cu, 0.5 Pb, 0.5 Bi	1.63	T 3
CS 11	148; British DTD 364	4 Cu, 0.8 Si, 0.8 Mn, 0.4 Mg	1.92 1.55 1.21	O T 6 T 4
CM 21	178; British BS 6L1	4 Cu, 0.5 Mg, 0.5 Mn	1.72 1.21	O T 4
	A 178	2.5 Cu, 0.3 Mg	1.55	T 4
	188; British BS 4L25, BS 2L42	4 Cu, 2 Ni, 0.5 Mg	1.93 1.55	O T 61
	B188	4 Cu, 1.5 Mg, 2.0 Ni	1.73 1.72	O T 72
CG 21	218; British BS 2L40, DTD 273	4.5 Cu, 1.5 Mg, 0.6 Mn	1.88 1.21	O T 4
	268	4.5 Cu, 0.8 Mn, 0.8 Si	1.55 1.93	T 6 O
	328	12.5 Si, 1.0 Mg, 0.9 Cu, 0.9 Ni	1.55 1.38	O T 6
	508	1.2 Mg	1.93 1.92	O H 38
	C608	1.3 Mg	1.55	O
	A 51 R	1.0 Si, 0.6 Mg, 0.25 Cr	2.09 1.72	O T 4
OR 1	828	2.5 Mg, 0.25 Cr	1.38 1.38	O H 38
	838	1.3 Mg, 0.7 Si, 0.25 Cr	1.72 1.55	O T 4
	868; British DTD 303	5.2 Mg, 0.1 Mn, 0.1 Cr	1.17 1.09	H 18 O
IS 21	618	1 Mg, 0.6 Si, 0.25 Cu, 0.25 Cr	1.72 1.55	T 4 O
	628	0.25 Cu, 0.6 Si, 1 Mg	1.72 1.55	T 4 O
	638	0.4 Cu, 0.7 Mg	1.93 2.09	T 42 T 8
2G 42	788	5.5 Zn, 2.5 Mg, 1.5 Cu, 0.3 Cr, 0.2 Mn	1.21	T 6
	R 301	1 Mg, 0.7 Si, 0.5 Mn	1.93 1.21	O T 4
	R 317	4 Cu, 0.5 Mn, 0.5 Mg, Pb, 0.5 Bi	1.55 1.72 1.21	T 6 O T 4

CASTING ALLOYS

SS	13	12 Si	1.55 to 1.21	
SA	43	8 Si	1.47	Annealed.
SC 2	85	5 Si, 4 Cu	1.17	Cast.
	108	4 Cu, 3 Si	1.21 1.47	Annealed.
SC 8	Alcast	8 Si, 3 Cu	1.06 1.17 1.13 1.38	Cast. Refined. Aged. T 7
SC 1	A108	5.5 Si, 4.5 Cu	1.42	
	112	7 Cu, 1.7 Zn	1.17 1.47	Annealed.
CS 22	113	7 Cu, 2 Si, 1.7 Zn	1.17 1.47	Annealed.
CS 22	C113	7 Cu, 3.5 Si	1.09	
CG 1	122	10 Cu, 0.2 Mg	1.59 1.30 1.34	T 2 T 61

Data from NBS Circular No. 556

ALUMINUM ALLOYS (Cont'd)  
COMPANY AND TRADE MANUALS

ASTM designation	Trade designation	Nominal composition (%)	Conductivity	State
			w/cm deg K	
SC 41	A 132	12 Si, 2.5 Ni, 1.2 Mg, 0.8 Cu	1.17	T 581
	D 132	9 Si, 3.5 Cu, 0.8 Mg, 0.8 Ni	1.09	T 5
	138	10 Cu, 4 Si, 0.3 Mg	1.05	T 21
CN 21	142	4 Cu, 2 Ni, 1.5 Mg	1.67 1.34 1.31 1.30 1.38 1.47 1.38	T 571 T 77 T 61 T 4 T 62 T 4
CI 1	195	4.5 Cu	1.42 to 1.49	T 6
CS 4	B 195	4.5 Cu, 2.5 Si	1.17 1.28 1.38	Annealed.
	212	8 Cu, 1.2 Si	1.34	
G 1	214; British DTD 165	3.8 Mg	1.42	
	A 214	3.8 Mg, 1.5 Zn	1.47	
	H 214	3.8 Mg, 1.8 Si	1.42	
	F 214	3.8 Mg, 0.5 Si	0.96	
	218	8 Mg	0.88	T 4
	220	10 Mg	1.13	
SC 8	319	6 Si, 3.5 Cu	1.05	F
	333	9 Si, 3.5 Cu	1.21 1.17 1.42 1.67 1.42 1.47 1.63	T 5 T 6 T 7 T 51 T 6 T 61 T 7
SC 21	355	6 Si, 1.3 Cu, 0.5 Mg	1.51 1.67 1.55 1.59 1.63	Chill T 6 T 51 T 6 T 7 Chill T 6
SG 1	356	7 Si, 0.3 Mg	1.13 to 1.47 0.96 to 1.09 0.96	
	360, A360	0.5 Si	1.59	
	380, A380	2 Si, 3.5 Cu	1.59	
	344	12 Si, 3.5 Cu	0.96	
	A612	6.5 Zn, 0.7 Mg, 0.5 Cu	1.59	
	C 612	6.5 Zn, 0.5 Cu, 0.4 Mg	1.80	
	750	6.5 Si, 1 Cu, 1.0 Ni		

TITANIUM ALLOYS

Cut	Composition (%)	Conductivity and Remarks	Reference
		w/cm deg K	
	2.5 Cr, 1 Fe	Abstract only; $k = 0.13$ at 273°K, 0.10 at 195°K, 0.06 at 80°K.	C. J. Rigney and L. I. Docketahler (1951).
Fig. 29; T.W.-Ti	Rem-Cru Titanium, RC 130-B; 4.7 Mn, 3.99 Al, 0.14 C.	R. cmf	W. W. Tyler and A. C. Wilson (1942).

TUNGSTEN

Composition	Conductivity and remarks	Reference
	w/cm deg K	
"Impure"	Single crystal; $k = 1.83$ at 83°K, 1.80 at 21°K.	R. Grünigern and E. Gooss (1927).

CHROMIUM  
COMPANY AND TRADE MANUALS

Composition	Conductivity
	w/cm deg K
Commercial . . .	k=0.67 at 20°C.

IRON

See figures 8 and 9 under "METALLIC ELEMENTS"

STEELS

The tables for steels are arranged into groups where the principal alloying metals are as follows: carbon; silicon; copper, chromium, cobalt, manganese, molybdenum, nickel, tungsten, vanadium; and aluminum.

CARBON STEELS

Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
0.1 C.....	k=0.67 at 18°C; wrought iron.	W. Jaeger and H. Desselhorst (1900).
1 C.....	k=0.45 at 18°C; wrought iron.	Do.
0.1 C, 0.06 Mn, 0.05 Cu, 0.02 Si, S, 0.03 P.	k=0.72 at 18°C.	B. Gruneisen (1900).
0.57 C, 0.2 Si, 0.1 Mn, 0.04 S, 0.03 Cu, 0.01 P.	k=0.82 at 18°C.	Do.
0.99 C, 0.1 Mn, 0.56 Si, 0.03 S, Cu.	k=0.51 at 18°C.	Do.
1.5 C, 0.2 Mn, 0.06 Si, 0.03 Cu, S, 0.01 P.	k=0.50 at 18°C.	Do.
1 C; "silver steel"...	See figure 23, curve with initial L.	C. H. Lees, (1908).

CARBON STEELS (Cont'd)

Composition (%) <sup>1</sup>	Conductivity <sup>1</sup>	State <sup>1</sup>
	w/cm deg K	
0.1 C, 0.4 Mn, 0.02 P, 0.02 S.....	0.60	
0.4 C, 0.3 Si, 0.4 Mn, 0.02 P, 0.02 S.....	.44	
0.7 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.....	.48	
0.9 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.....	.42	
1.0 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.....	.42	
1.2 C, 0.3 Si, 0.1 Mn, 0.03 P, 0.02 S.....	.40	
1.4 C, 0.3 Si, 0.2 Mn, 0.03 P, 0.02 S.....	.39	
2.41 C, 0.12 Si, 0.05 Mn, 0.04 P, 0.06 S.....	.32	As cast.
	.33	Annealed 1,000°C, 2 hr.
	.33	6 hr.
	.33	8 hr.

Data from NBS Circular No. 556.

CARBON STEELS (Cont'd)

Composition (%) <sup>1</sup>	Conductivity <sup>1</sup>	State <sup>1</sup>
	w/cm deg K	
2.53 C, 0.05 Si, 0.02 Mn, 0.01 P, 0.03 S.....	.31	As cast.
2.67 C, 0.1 <sup>1</sup> Si, 0.02 Mn, 0.03 P, 0.06 S.....	.30	Do.
	.32	1,000°C annealed, 2 hr.
	.32	6 hr.
	.32	8 hr.
3.12 C, 0.06 Si, 0.05 Mn, 0.02 P, 0.06 S.....	.26	As cast.
3.14 C, 0.01 Si, 0.03 Mn, 0.02 P, 0.03 S.....	.26	Do.
3.17 C, 0.21 Si, 0.03 Mn, 0.04 P, 0.06 S.....	.25	Do.
	.26	Annealed 1,000°C, 2 hr.
	.26	6 hr.
	.27	8 hr.
3.53 C, 0.04 Si, 0.05 Mn, 0.01 P, 0.05 S.....	.23	As cast.
3.64 C, 0.16 Si, 0.04 Mn, 0.02 P, 0.02 S.....	.21	Do.
	.23	Annealed 1,000°C, 2 hr.
	.23	8 hr.
	.23	8 hr.
3.93 C, 0.15 Si, 0.04 Mn, 0.02 P, 0.05 S.....	.20	As cast.
3.95 C, 0.2 Si, 0.56 Mn, 0.01 P, 0.02 S.....	.19	As cast.
	.21	Annealed 1,000°C, 2 hr.
	.26	6 hr.
	.50	8 hr.
4.13 C, 0.10 Si, 0.03 Mn, 0.02 P, 0.02 S.....	.18	As cast.
4.26 C, 0.10 Si, 0.03 Mn, 0.02 P, 0.02 S.....	.20	Annealed 1,000°C, 2 hr.
	.17	As cast.
4.33 C, 0.35 Si, 0.08 Mn, 0.02 P, 0.02 S.....	.19	Annealed 1,000°C, 2 hr.
	.18	As cast.
4.40 C, 0.31 Si, 0.03 Mn, 0.02 P, 0.08 S.....	.17	Annealed 1,000°C, 2 hr.
4.61 C, 0.37 Si, 0.03 Mn, 0.02 P, 0.04 S.....	.17	As cast.
4.63 C, 0.44 Si, 0.08 Mn, 0.02 P, 0.07 S.....	.15	Annealed 1,000°C, 2 hr.
3.53 C, 1.24 Si, 0.09 Mn, 0.01 P, 0.06 S.....	.13	As cast.
3.81 C, 1.96 Si, 0.08 Mn, 0.05 S.....	.13	Annealed 800°C, 1 hr.
	.35	As cast.
	.40	Annealed 800°C, 1 hr.
		Add. annealed 1,000°C 1 hr.
3.54 C, 1.98 Si, 0.06 Mn, 0.01 S.....	.43	As cast.
	.52	Annealed 800°C, 1 hr.

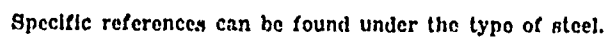
<sup>1</sup> Results by H. Masumoto (1927) at 25°C.

CARBON STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
Fig. 24; Mkl.	0.14 C, 0.08 Si, 0.07 Mn.	"Mild steel"; heated to 800°C and furnace-cooled.	J. de Nodel (1951).
Fig. 23; P. Z. J., SAE 1020.	0.23 Mn, 0.18 C, 0.014 Si		R. W. Powers, J. R. Ziegler, H. L. Johnston (1951a).
Fig. 23; P. Z. J., SAE 1095.	0.93 C, 0.34 Mn, 0.22 Si, 0.1 Ni, Cr, 0.06 Mo.		Do.

CARBON STEELS (Cont'd)  
COMPANY AND TRADE MANUALS

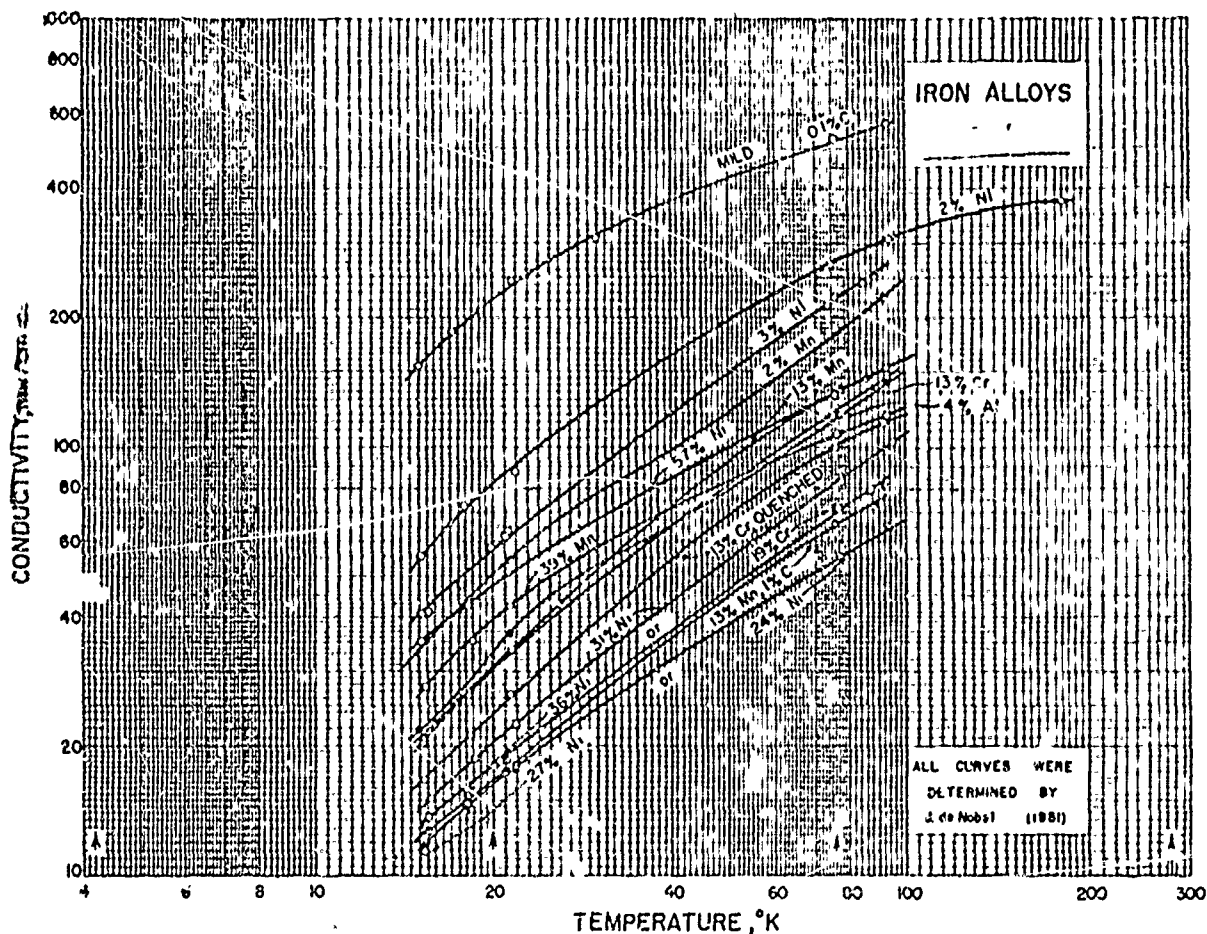
Composition (%)	Conductivity
	w/cm deg K
0.06 C, 0.045 Cr, 0.07 Ni, 0.31 Mo, 0.02 Mn	0.59
0.23 C, trace Cr, 0.074 Ni, 0.635 Mn, 0.13 Cu.	.52
0.115 C, trace Cr, 0.053 Ni, 0.613 Mn, 0.12 Cu.	.52
0.80 C, 0.11 Cr, 0.13 Ni, 0.32 Mn, 0.97 Cu, 0.01 Mo	.49
1.22 C, 0.11 Cr, 0.13 Ni, 0.35 Mn, 0.01 Mo, 0.08 Cu	.45



### CORROSION RESISTING STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
Fig. 24; 2% Ni.	99.2 Ni, 0.72 Mn, 0.21 Si, 0.14 C.	Heated to 800°C. and furnace-cooled.	J. de Nobel (1951).
24% Ni. . . .	24.50 Ni, 5.06 Mn, 1.16 C.	Heated to 1,050°C. and water-quenched.	Do.
27% Ni . . . .	27.20 Ni, 14.6 Cr, 3.5 W, 1.02 Si, 1.34 Mn, 0.44 C.	Heated to 1,000°C. and water-quenched, "crs./AIV".	Do.
31% Ni. . . . .	31.4 Ni, 0.82 Mn, 0.7 C.	Heated to 800°C. and furnace-cooled.	Do. Do.
35% Ni . . . . .	35.17 Ni, 0.93 Mn, 0.16 C, 0.09 Si.	Heated to 1,050°C. and water-quenched.	Do.
57% Ni. . . . .	57.5 Ni, 1.31 Mn, 0.31 C, 0.14 Si.	As forged; "A.M.S.". .	Do.
2% Mn. . . . .	2.23 Mn, 0.41 C, 0.07 H.	Heated to 800°C. and furnace-cooled.	Do.
13% Mn, 1% C.	12.69 Mn, 1.27 C, 0.12 Si.	Heated to 2,000°C. and water-quenched, "manganese steel".	Do. Do.
13% Mn . . . .	12.93 Mn, 0.10 S, 0.12 Si, 0.09 C, 0.03 P.	Heated to 1,000°C. and water-quenched.	Do.
30% Mn . . . .	30.9 Mn, 0.7 Si, 0.2 C, 0.05 S, 0.01 P.	.....do.....	Do.

FIGURE 89



Specific references can be found under the type of steel.

#### CORROSION RESISTING STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
13% Cr...	13.5 Cr, 0.28 C, 0.22 Ni, 0.13 Mn.	Heated to 800°C and furnace-cooled.	J. de Nobil (1951).
13% Cr, quenched.	do.	Heated to 950°C, oil quenched, reheated to 480°C, air-cooled.	Do.
18% Cr.....	18.8 Cr, 2.1 Ni, 0.43 Si, 0.31 Mn, 0.12 C.	Heated to 1,160°C and water-quenched.	Do.
3% Ni.....	2.61 Ni, 0.78 Mo, 0.49 Cr, 0.45 Mn, 0.37 C, 0.11 Si, 0.03 P, 0.01 S.	Heated to 850°C, oil quenched, reheated to 650°C, water-quenched.	Do.
Fig. 23; P.Z.J.-1A-K 4130.	0.98 Cr, 0.42 Mn, 0.33 C, 0.25 Ni, and Mo esch.		R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951a).
P.Z.J.-410...	12.8 Cr, 0.36 P, 0.37 Mn, 0.17 Ni, 0.02 C, 0.04 Cu, 0.02 N, 0.01 P.		Do.

#### CORROSION RESISTING STEELS (Cont'd)

Curve	Composition (%)	Remarks	Reference
P.Z.J.-347...	17.85 Cr, 10.28 Ni, 1.24 Mn, 0.85 Nb, 0.67 Si, 0.28 Cu, 0.06 C, 0.03 N, 0.02 P.		R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951a).
P.Z.J.-304...	18.68 Cr, 8.84 Ni, 1.12 Mn, 0.43 Si, 0.06 Cu, 0.06 C, 0.03 N, 0.02 P.		Do.
Fig. 23; B.-Steinle...	7.8 Ni, 18.9 Cr, 1 Ti, 0.7 Si, 0.1 C.	Austenite grains about 0.01 mm across.	R. Bertram (1951b).
Fig. 23; Es. 21-303.	18 Cr, 9 Ni, 0.16 C.		I. Estermann and J. E. Zimmermann (1952).
Es. 21-347	18 Cr, 10 Ni, 0.5 Nb, 0.04 C.		Do.
T.W.-316	17 Cr, 12 Ni, 2.8 Mo, 0.1 C.	25% cold reduction.	W. W. Tyler and A. C. Wilson (1952).

Data from NBS Circular No. 556.

FIGURE 90

**CORROSION RESISTING STEELS (Cont'd)**  
**COMPANY AND TRADE MANUALS**

AT&T No	Nominal composition (%)	Conductivity
		w/cm deg K
008	0.05 C, 0.5 Cr, 0.07 Ni, 0.21 Mn, 0.02 Mo	0.59
023	0.23 C, trace Cr, 0.74 Ni, 0.38 Mn, 0.13 Cu	.53
048	0.48 C, trace Cr, 0.03 Ni, 0.43 Mn, 0.12 Cu	.52
0325	0.325 C, 0.17 Cr, 3.17 Ni, 0.56 Mn, 0.09 Cu, 0.04 Mo	.37
031	0.31 C, 0.75 Cr, 3.43 Ni, 0.55 Mn, 0.39 Mo, 0.05 Cu	.33
0315	0.315 C, 1.72 Cr, 0.073 Ni, 0.69 Mn, 0.12 Mo, 0.07 Cu	.48
035	0.35 C, 0.68 Cr, 0.26 Ni, 0.59 Mn, 0.3 Mo, 0.12 Cu	.43
3	0.3 Cr, 0.5 Mo	.37
122	0.122 C, 0.03 Cr, 0.07 Ni, 0.10 Mn, 0.22 Si, 0.07 Cu	.13
028	0.28 C, trace Cr, 28.37 Ni, 0.89 Mn, 0.15 Si, 0.03 Cu	.13
005	0.05 C, 10.11 Cr, 8.11 Ni, 0.37 Mn, 0.69 Si, 0.6 W, 0.03 Cu	.16
013	0.13 C, 12.95 Cr, 0.14 Ni, 0.25 Mn, 0.17 Si, 0.06 Cu, 0.01 V	.27
027	0.27 C, 13.69 Cr, 0.21 Ni, 0.28 Mn, 0.25 W, 0.02 V	.26
0716	0.716 C, 1.26 Cr, 0.067 Ni, 0.35 Mn, 0.45 W, 0.08 V	.25
014	0.14 C, 18 Cr, 0 Ni, 2 Mo	.22
015	0.15 C, 18 Cr, 0 Ni, 0.07 P, S, Se each, 0.6 Zr, Mo each	.22
020	0.20 C, 23 Cr, 13 Ni, 3 Mn	.18
015	0.15 C, 12.5 Cr	.40
015	0.15 C, 13 Cr, 0.07 P, S, Se each, 0.6 Zr, Mo each	.40
015	0.15 C or more, 13 Cr	.33
012	0.12 C, 16 Cr	.30
07	0.7 C, 17 Cr, 0.75 Mo	.25
15	15 Cr, 35 Ni	.13

**NICKEL ALLOYS**  
**COMPANY AND TRADE MANUALS**

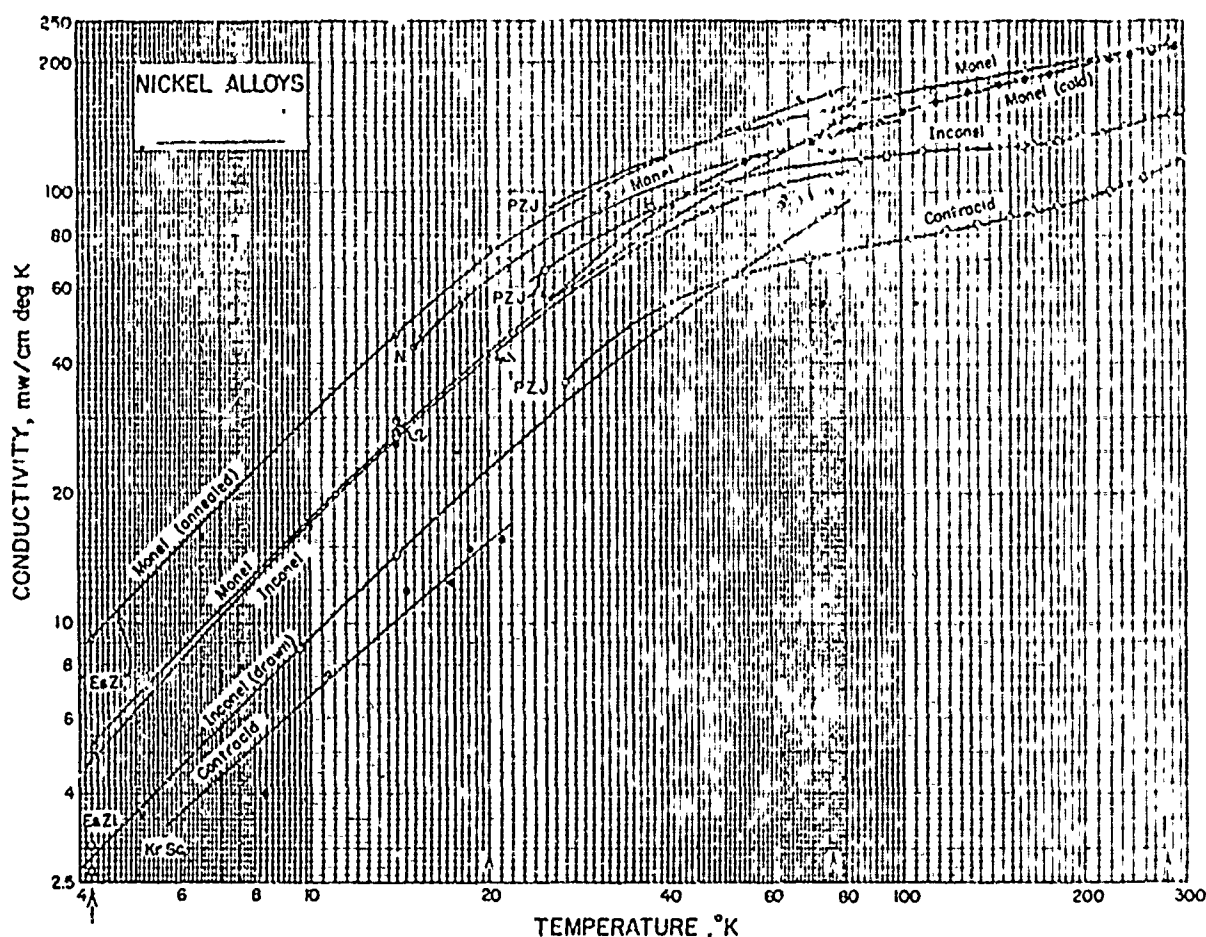
Trade Designation	Nominal composition (%)	Conductivity
		w/cm deg K
A Nickel	99.1 Ni + Cu, 0.2 Mn, 0.15 Fe, 0.1 Cu, 0.1 C	0.61
D Nickel	95 Ni, 4.5 Mn	.48
Moon	07 Ni, 30 Cu, 1.4 Fe, 0.15 Mn, 0.15 C, 0.1 Si	.26
K Moon	66 Ni, 29 Cu, 2.75 Al, 0.9 Fe, 0.75 Mn, 0.5 Si, 0.15 C	.19
Hastelloy A	57 Ni, 20 Mo, 20 Fe	.17
Hastelloy B	62 Ni, 30 Mo, 5 Fe	.11
Hastelloy C	58 Ni, 17 Mo, 15 Cr, 5 W, 5 Fe	.13
Hastelloy D	85 Ni, 10 Si, 3 Cu	.21
Inconel	70 Ni, 14 Cr, 6 Fe	.15
Inconel	58 Ni, 22 Cr, 6 Cu, Mo, Fe each	.12
Monel	90 Ni, 10 Cu	.56
Monel	60 Ni, 24 Fe, 16 Cr	.14
Monel	35 Ni, 50 Fe, 15 Cr	.13
Constantan	45 Ni, 55 Cu	.23

**DEOXIDIZED STEELS**  
**(Aluminum)**

Curve	Composition (%)	Remarks	Reference
Fig. 24; 4% Al	4.11 Al, 0.13 Si, 0.08 Mn, 0.03 C, 0.91 S	Heated to 900°C and furnace-cooled.	J. de Nobel (1951).

Data from NRS Circular No. 556

TABLE XLIV



NICKEL ALLOYS (Cont'd)

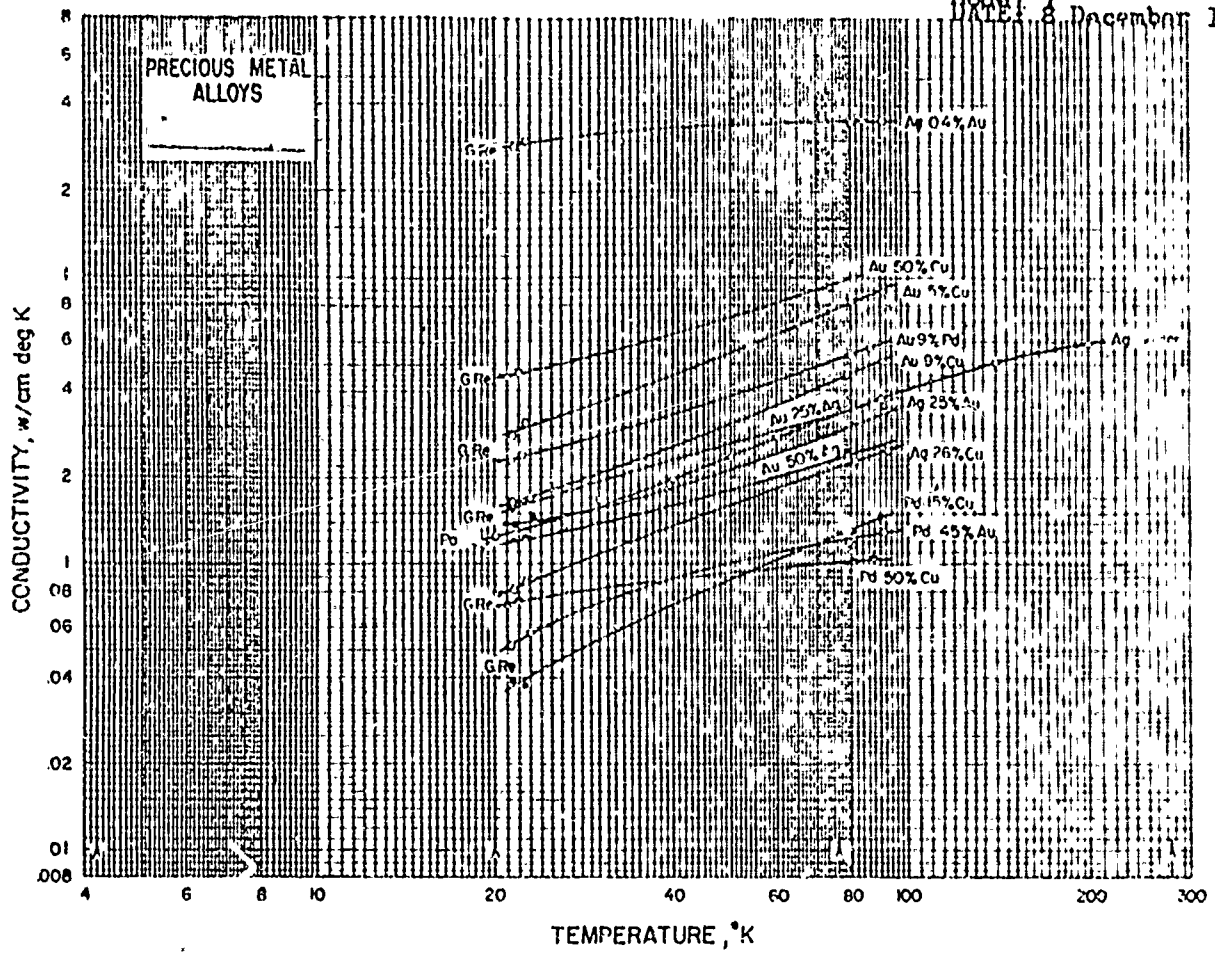
Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
.....	87.0 Ni, 1.4 Co, 1 Mn, 0.4 Fe	$k=0.59$ at 18°C	W. Jager and H. Humelhorst (1900).
.....	80 Ni, 20 Cr; "nichrome"	$k=0.31$ above room temperature.	R. Kikuchi (1932).
.....	70 Ni, 19 Cr, 12 Fe	$k=0.28$ above room temperature.	Do.
Fig. 28; Kr. Sc. Contraloid.	80 Ni, 16 Cr, 16 Fe, 7 Mo		J. Kuzwil and K. Schifer (1939).
P.Z.J.-Inconel.	80 Ni, 14 Cr, 6 Fe		R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951c).
P.Z.J.-Contraloid.	80.0% Ni, 14.74 Cr, 15.82 Fe, 7.2 Mo, 2.14 Mn, 0.04 C		Do.
P.Z.J.-Monel.	87 Ni, 30 Co, 1.4 Fe, 1.0 Mn, 0.15 C, 1.2 S, .01 S	Hot-rolled.	Do.
P.Z.J.-Monel, cold.	..do..	Cold-rolled	Do.

NICKEL ALLOYS (Cont'd)

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
.....	Commercial; 99.4 Ni	See Fig. 8 and Nickel Table under "Metallurgical Elements".	J. de Nobel (1951).
N.-Monel. ....	87 Ni, 30.2 Cu.	As forged	Do.
Fig. 24; 87% Ni.	87.5 Ni, 1.31 Mn, 0.34 C, .14 Si; remainder Fe, approx. 40.	As forged	Do.
Fig. 28; Ea. Zi.-Inconel (drawn).	Inconel	Hard-drawn	I. Pottermann and J. E. Zimmerman (1952).
Ea. Zi.-Inconel, #1.	do	Annealed	Do.
Ea. Zi.-Inconel, #2.	do	Hot-rolled	Do.
Ea. Zi.-Monel	Monel	Hard-drawn	Do.
Ea. Zi. Monel, (annealed).	Monel	Annealed	Do.

Data from NBS Circular No. 556

FIGURE 91



**PRECIOUS METAL ALLOYS**  
See also the tables given under "SILVER ALLOYS"  
and "GOLD ALLOYS".

PALLADIUM ALLOYS		
Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
90 Pd, 10 Ag.....	k=0.48 at 25°C.....	F. A. Schulze (1911).
80 Pd, 20 Ag.....	k=0.37 at 25°C.....	Do.
70 Pd, 30 Ag.....	k=0.28 at 25°C.....	Do.
60 Pd, 40 Ag.....	k=0.27 at 25°C.....	Do.
50 Pd, 50 Ag.....	k=0.22 at 25°C.....	Do.
90 Pd, 10 Au.....	k=0.52 at 25°C.....	Do.
80 Pd, 20 Au.....	k=0.42 at 25°C.....	Do.
70 Pd, 30 Au.....	k=0.40 at 25°C.....	Do.
60 Pd, 40 Au.....	k=0.38 at 25°C.....	Do.
50 Pd, 50 Au.....	k=0.36 at 25°C.....	Do.
90 Pd, 10 Pt.....	k=0.64 at 25°C.....	Do.
80 Pd, 20 Pt.....	k=0.46 at 25°C.....	Do.
70 Pd, 30 Pt.....	k=0.40 at 25°C.....	Do.
60 Pd, 40 Pt.....	k=0.38 at 25°C.....	Do.
50 Pd, 50 Pt.....	k=0.37 at 25°C.....	Do.

PALLADIUM ALLOYS (Cont'd)		
Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
Commercial .....	k=0.42 at 17°C.....	T. Barlett and R. M. Winter (1925)
85 Pd, 14.5 Cu .....	Polycrystalline; see Fig. 26, "Pd-15% Cu".	F. Gillesen and H. Baldemann (1934).
50 Pd, 50 Cu.....	Annealed; see Fig. 26, "Pd-50% Cu" .....	Do.
55 Pd, 45 Au .....	Annealed 2 hr. at 800°C; see Fig. 26, "Pd-45% Au".	Do.

PLATINUM ALLOYS		
"Impure".....	k=0.816 at 15°C.....	W. Jager and H. Derschelhorst (1900).
90 Pt, 10 Pd ..	k=0.43 at 25°C.....	F. A. Schulze (1911).
80 Pt, 20 Pd ..	k=0.42 at 25°C.....	Do.
70 Pt, 30 Pd ..	k=0.38 at 25°C.....	Do.
60 Pt, 40 Pd ..	k=0.34 at 25°C.....	Do.
50 Pt, 50 Pd ..	k=0.32 at 25°C.....	Do.

Data from NBS Circular No. 556

FIGURE 92

TABLE XIV

PLATINUM ALLOYS (Cont'd)		
Composition (%)	Conductivity and remarks	Reference
	w/cm deg K	
70 Pt, 10 Ir ..	$k=0.31$ at $17^{\circ}\text{C}$ .. .	T. Barratt and R. M. Winter (1925).
65 Pt, 15 Ir....	$k=0.23$ at $17^{\circ}\text{C}$ .....	Do.
80 Pt, 20 Ir....	$k=0.18$ at $17^{\circ}\text{C}$ .....	Do.
90 Pt, 10 Rh ..	$k=0.30$ at $17^{\circ}\text{C}$ .. .	Do.
96 atomic % Pt, 4 atomic % Au.	$k=0.46$ at $18^{\circ}\text{C}$ .. .	C. H. Johanson and J. O. Linde (1930).
90 atomic % Pt, 10 atomic % Au.	$k=0.35$ at $18^{\circ}\text{C}$ .....	Do.
75 atomic % Pt, 25 atomic % Au.	$k=0.24$ at $18^{\circ}\text{C}$ .....	Do.
55 atomic % Pt, 45 atomic % Au.	$k=0.21$ at $18^{\circ}\text{C}$ .....	Do.

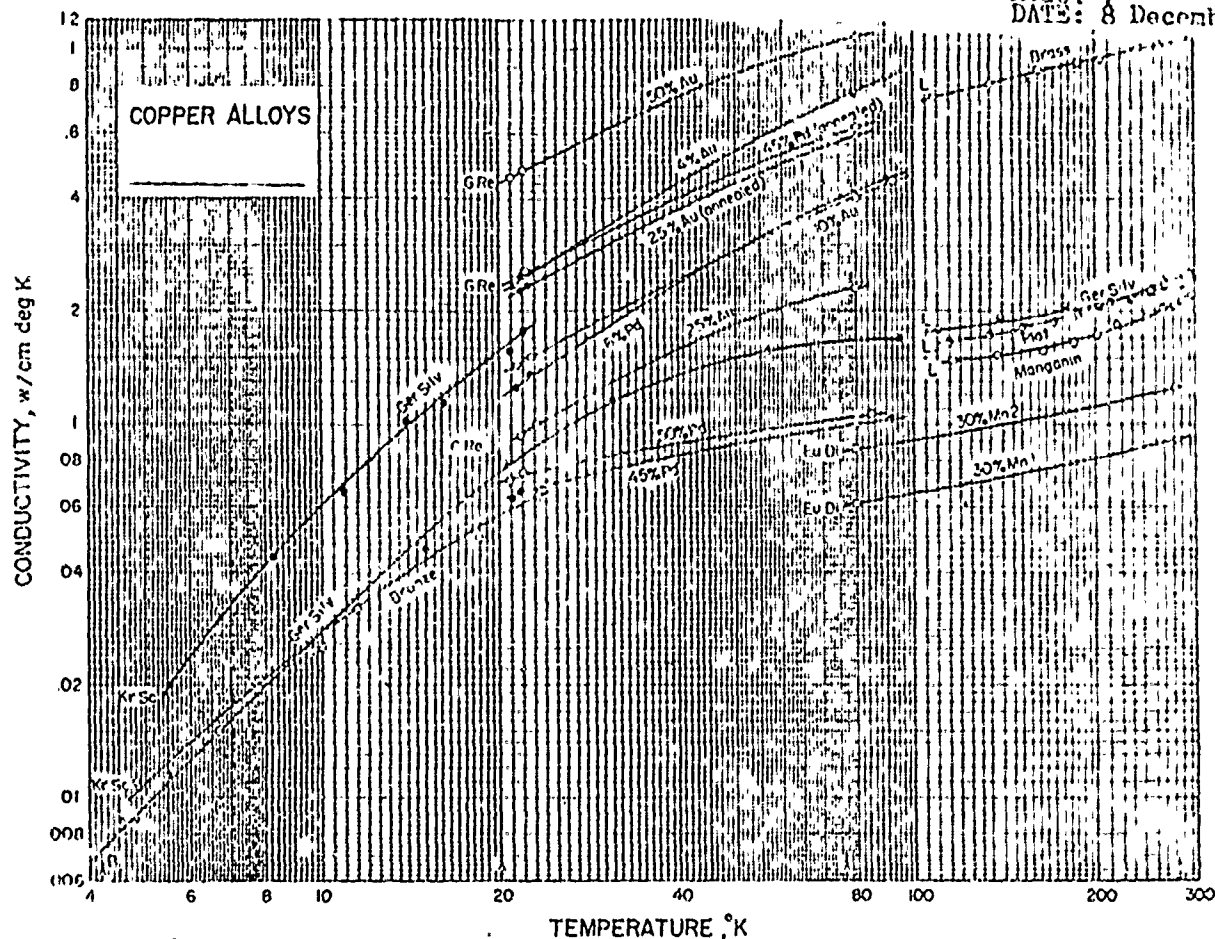
COPPER ALLOYS  
See also the "COPPER-NICKEL ALLOY" graph and tables.

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
.....	About 62 Cu, 15 Ni, 22 Zn.	"Neusilber"; $k=0.29$ at $0^{\circ}\text{C}$ .	L. Lorenz (1881).
.....	About 82 Cu, 18 Zn.	"Red brass"; $k=1.04$ at $0^{\circ}\text{C}$ .	Do.
.....	About 65 Cu, 35 Zn.	"Yellow brass"; $k=0.85$ at $0^{\circ}\text{C}$ .	Do.
.....	0.34 P .....	$k=0.95$ at $15^{\circ}\text{C}$ .....	A. Rietach (1900).
.....	0.87 P.....	$k=0.61$ at $15^{\circ}\text{C}$ .....	Do.
.....	1.75 P.....	$k=0.53$ at $15^{\circ}\text{C}$ .....	Do.
.....	2.03 P.....	$k=0.34$ at $15^{\circ}\text{C}$ .....	Do.
.....	2.35 P.....	$k=0.27$ at $15^{\circ}\text{C}$ .....	Do.
.....	5.35 P.....	$k=0.15$ at $15^{\circ}\text{C}$ .....	Do.
.....	1.04 As.....	$k=1.14$ at $15^{\circ}\text{C}$ .....	Do.
.....	1.80 As.....	$k=0.92$ at $15^{\circ}\text{C}$ .....	Do.
.....	2.66 As.....	$k=0.64$ at $15^{\circ}\text{C}$ .....	Do.
.....	3.00 As.....	$k=0.54$ at $15^{\circ}\text{C}$ .....	Do.
.....	5.02 As.....	$k=0.20$ at $15^{\circ}\text{C}$ .....	Do.
.....	66.7 Cu, 7.15 Zn, 6.33 Sn, 0.8 Ni.	"Red brass"; $k=0.60$ at $18^{\circ}\text{C}$ .	W. Jagger and H. Dinnelhorst (1900).
.....	84 Cu, 12 Mn, 4 Ni..	$k=0.22$ at $18^{\circ}\text{C}$ .. .	Do.
Fig. 27; L-brass.	70 Cu, 30 Zn. ....	.....	C. H. Lee (1908).
Fig. 27; L-Ger. silv.	62 Cu, 22 Zn, 15 Ni..	"German silver".....	Do.
L-Plat .....	Approx. same as above.	"Platoid".....	Do.
L-Manganese	84 Cu, 12 Mn, 4 Ni..	"Manganese".....	Do.
.....	82 Cu, 18 Zn.....	"Red brass"; "50c" crystals; $k=1.27$ at $273^{\circ}\text{K}$ , 0.65 at $90^{\circ}\text{K}$ .	A. Eucken and O. Neumann (1924).
.....	.....do.....	"Red brass"; "large" crystals; $k=1.30$ at $273^{\circ}\text{K}$ , 0.65 at $90^{\circ}\text{K}$ .	Do.

COPPER ALLOYS (Cont'd)			
Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
Eu. Di.-Cu-50% Mn, 1.	70 Cu, 30 Mn ..	About 45 crystals per centimeter.	A. Eucken and K. Dittich (1927).
Eu. Di.-Cu-50% Mn, 2.	do .. ..	About 112 crystals per centimeter.	Do.
.....	3 Ag.....	Unannealed; $k=2.57$ at $83^{\circ}$ and $21^{\circ}\text{K}$ .	E. Gruneisen and H. Reddemann (1934).
.....	.....do.....	Annealed 3 hr at $390^{\circ}\text{C}$ ; $k=4.06$ at $83^{\circ}\text{K}$ , 6.19 at $21^{\circ}\text{K}$ .	Do.
Fig. 27; G. Re.-4% Au.	95.5 Cu, 4.5 Au ..	Polycrystalline; unannealed.	E. Gruneisen and H. Reddemann (1934).
G. Re.-10% Au.	90.3 Cu, 9.7 Au.....	Polycrystalline; unannealed.	Do.
.....	75.1 Cu, 24.9 Au ..	Quenched from $800^{\circ}\text{C}$ ; $k=0.34$ at $83^{\circ}\text{K}$ .	Do.
.....	.....do.....	Annealed 20 hr at $400^{\circ}\text{C}$ ; $k=0.61$ at $83^{\circ}\text{K}$ .	Do.
.....	.....do.....	Annealed 32 hr at $360^{\circ}\text{C}$ ; $k=0.63$ at $83^{\circ}\text{K}$ .	Do.
.....	.....do.....	Same as above except later annealed 2 hr at $820^{\circ}\text{C}$ , then quenched; $k=0.23$ at $83^{\circ}\text{K}$ .	Do.
G. Re.-25% Au.	.....do.....	Same as above except later annealed 5 months at room temperature.	Do.
G. Re.-35% Au, annealed.	.....do.....	Same as above except additionally annealed 30 hr at $320^{\circ}\text{C}$ .	Do.
G. Re.-Cu-60% Au.	49.9 Cu, 50.1 Au.....	Annealed 30 hr at $320^{\circ}\text{C}$ ..	Do.
G. Re.-Cu-50% Pd.	49.9 Cu, 50.1 Pd.....	Annealed.....	Do.
G. Re.-6% Pd.	93.6 Cu, 6.4 Pd.....	Polycrystalline; unannealed.	Do.
.....	55 Cu, 45 Pd.....	Annealed; $k=0.57$ at $83^{\circ}\text{K}$ .	Do.
G. Re.-48% Pd.	.....do.....	Annealed 2 hr at $800^{\circ}\text{C}$ ..	Do.
G. Re.-48% Pd, (annealed).	.....do.....	Further annealed 30 hr at $320^{\circ}\text{C}$ .	Do.

COPPER ALLOYS (Cont'd)	
Composition (%) <sup>1</sup>	Conductivity <sup>1</sup>
	w/cm deg K
99.985 Cu, 0.0015 Fe, .02 Os.....	3.03 "
99.80 Cu, 0.19 Fe, .02 Fe .....	2.13 "
99.78 Cu, 0.23 Sn, .02 Fe .....	1.92 "
99.65 Cu, 0.32 Sn, .032 Fe .....	1.65 "
99.53 Cu, 0.45 Sn, .03 Fe .....	1.29 "
99.04 Cu, 1.00 Sn, 0.03 Fe .....	0.82 "
98.08 Cu, 1.98 Sn, 0.06 Fe .....	0.51 "
96.00 Cu, 3.91 Sn, 0.02 Fe .....	0.34 "

<sup>1</sup> These values were determined by C. R. Smith (1935) at  $20^{\circ}\text{C}$ . Sometimes the composition percentages add up to more than 100.  
<sup>2</sup> The copper-nickel alloys were hot-rolled, cold-drawn and annealed at  $700^{\circ}\text{C}$  and were in the homogeneous  $\alpha$  solid solution.



COPPER ALLOYS (Cont'd)

Composition (%) <sup>1</sup>	Conductivity <sup>1</sup> w/cm deg K
99.95 Cu, 0.05 Al, .01 Fe.....	3.52 <sup>1</sup>
99.77 Cu, 0.22 Al, .01 Fe.....	2.91 <sup>1</sup>
99.47 Cu, 0.47 Al, .02 Fe.....	2.35 <sup>1</sup>
99.20 Cu, 0.71 Al, .03 Fe.....	1.75 <sup>1</sup>
98.08 Cu, 1.89 Al, 0.03 Fe.....	1.21 <sup>1</sup>
95.28 Cu, 4.61 Al, 0.14 Fe.....	0.83 <sup>1</sup>
92.15 Cu, 7.72 Al, 0.13 Fe.....	0.72 <sup>1</sup>
90.80 Cu, 9.37 Al, 0.07 Fe.....	0.65 <sup>1</sup>
89.88 Cu, 10.00 Al, 0.22 Fe.....	0.60 <sup>1</sup>
87.76 Cu, 12.16 Al, 0.08 Fe.....	0.51 <sup>1</sup>
86.01 Cu, 0.07 Mn, .01 Fe, .02 Mg.....	3.42 <sup>1</sup>
99.88 Cu, 0.14 Mn, .01 Fe, .01 Mg.....	3.28 <sup>1</sup>
99.55 Cu, 0.43 Mn, .01 Fe, .01 Mg.....	2.58 <sup>1</sup>
99.05 Cu, 1.05 Mn, 0.01 Fe, .01 Mg.....	1.50 <sup>1</sup>
98.27 Cu, 1.77 Mn, 0.03 Fe, .01 Mg.....	1.02 <sup>1</sup>
95.71 Cu, 4.45 Mn, 0.06 Fe, .02 Mg.....	0.79 <sup>1</sup>
90.25 Cu, 9.61 Mn, 0.18 Fe, .02 Mg, .021 C <sup>2</sup> .....	0.26 <sup>1</sup>
80.03 Cu, 19.82 Mn, 0.00 Fe, .02 Mg, .035 C <sup>2</sup> .....	0.15 <sup>1</sup>

<sup>1</sup>These values were determined by C. S. Smith (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

<sup>2</sup>The copper-aluminum alloys were rolled and annealed at 700°C and were in the  $\alpha$  solid solution (except the 12% Al, which was  $\delta$ ).

<sup>3</sup>The copper-manganese alloys were desolved with magnesium, hot-rolled, and annealed at 700°C.

COPPER ALLOYS (Cont'd)

Composition (%) <sup>1</sup>	Conductivity <sup>1</sup> w/cm deg K	State <sup>1</sup>
99.95 Cu, 0.05 Fe, .02 Cu.....	3.91 <sup>1</sup>	
98.24 Cu, 33.72 Zn, 0.01 Pb, .01 Fe, .001 B.....	1.20 <sup>1</sup>	
99.94 Cu, 3.01 Zn, 0.02 Fe.....	2.68 <sup>1</sup>	
98.21 Cu, 4.77 Zn, 0.02 Fe.....	2.42 <sup>1</sup>	
97.49 Cu, 0.05 Fe, .27 Ni, 2.24 He.....	0.56 <sup>1</sup>	Quenched
97.49 Cu, 0.05 Fe, .27 Ni, 2.24 He.....	1.03 <sup>1</sup>	Reheated.
97.49 Cu, 0.05 Fe, .27 Ni, 2.24 He.....	0.74 <sup>1</sup>	Quenched, cold-drawn
97.49 Cu, 0.05 Fe, .27 Ni, 2.24 He.....	0.82 <sup>1</sup>	Reheated.
97.49 Cu, 0.05 Fe, .27 Ni, 2.24 He.....	1.60 <sup>1</sup>	
85.10 Cu, 12.97 Zn, 1.88 Pb, 0.05 Fe.....	1.08 <sup>1</sup>	
61.85 Cu, 34.70 Zn, 3.20 Pb, 0.07 Fe.....	1.11 <sup>1</sup>	
85.09 Cu, 29.18 Zn, 4.02 Pb, 0.01 Fe.....	0.50 <sup>1</sup>	
88.07 Cu, 3.70 Zn, 3.77 Sn, 3.83 Pb, 0.01 Fe.....	0.56 <sup>1</sup>	
95.09 Cu, 4.09 Zn, 3.76 Sn, 3.83 Pb, 0.02 Fe, .25 P.....	1.00 <sup>1</sup>	
60.41 Cu, 37.09 Zn, 1.03 Sn, 1.12 Pb, 0.02 Fe, .18 Al, .21 S.....	0.30 <sup>1</sup>	Chill-cast.
86.01 Cu, 25.91 Zn, 0.18 Mn, 17.95 Ni, 0.04 Fe, .02 C <sup>2</sup> .....	31 <sup>1</sup>	
63.76 Cu, 19.70 Zn, 0.18 Mn, 16.29 Ni, 0.14 Fe.....	46 <sup>1</sup>	
63.51 Cu, 23.84 Zn, 0.18 Mn, 10.36 Ni, 0.08 Fe, .01 C <sup>2</sup> .....	42 <sup>1</sup>	
59.76 Cu, 29.88 Zn, 0.16 Mn, 10.13 Ni, 0.01 Fe, .01 Mg.....	59 <sup>1</sup>	
61.01 Cu, 30.50 Zn, 5.41 Ni, 0.03 Fe.....		

<sup>1</sup>These values were determined by C. S. Smith (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

<sup>2</sup>The miscellaneous alloys were extensively worked, annealed, and slowly cooled except where noted.

Data from NBS Circular No. 556.

FIGURE 93

TABLE XLVI

COPPER ALLOYS (Cont'd)

Composition (%)	Conductivity	State
	w/cm deg K	
56.57 Cu, 17.65 Zn, 13.24 Ni, 0.10 Fe, 2.21 Sn, 10.11 Pb	.31	Sand-cast.
89.08 Cu, 1.88 Ni, 0.03 Fe, 5.11 Al, 0.71 Sn	.15	Quenched
89.08 Cu, 1.88 Ni, 0.03 Fe, 5.11 Al, 0.71 Sn	.57	Reheated.
89.08 Cu, 1.88 Ni, 0.03 Fe, 5.11 Al, 0.71 Sn	.66	Furnace-cooled
56.13 Cu, 42.31 Zn, 1.02 Ni, 0.19 Fe	1.14	
89.38 Cu, 0.31 Ni, 0.52 Fe, .38 Sn, 9.41 Al	1.60	
75.79 Cu, 22.22 Zn, 0.01 Fe, 1.98 Al	1.00	
52.35 Cu, 38.36 Zn, 0.12 Mn, 1.06 Fe, 0.91 Sn, .13 Pb	1.01	
99.651 Cu, 0.03 Fe, .32 Sn	1.65	
95.61 Cu, 1.51 Mn, 0.11 Fe	0.16	
99.21 Cu, 0.01 Fe, .01 Sn, .85 Cd	3.45	
98.41 Cu, 0.02 Fe, .59 Sn, .02 Ni, 1.07 Cd	2.33	
72.49 Cu, 17.76 Zn, 3.31 Mn, 1.78 Fe, 4.14 Al	0.50	
94.00 Cu, 1.03 Mn, 0.08 Fe, 4.68 Sn	0.23	Sand-cast.
95.69 Cu, 0.99 Mn, 0.16 Fe, 3.23 Sn	0.33	
95.10 Cu, 0.30 Mn, 0.06 Fe, 1.50 Sn	0.54	
81.55 Cu, 14.21 Zn, 0.20 Mn, 0.01 Fe, 4.09 Sn	0.28	Chill-cast.
95.53 Cu, 1.12 Zn, 0.02 Fe, 3.11 Sn	0.12	
78.30 Cu, 0.20 Ni, 8.04 Sn, 13.35 Pb, 0.1 P	0.12	Sand-cast.
87.86 Cu, 3.05 Zn, 0.03 Fe, .87 Sn	2.54	Sand-cast.
88.36 Cu, 1.90 Zn, 0.07 Fe, 9.55 Sn	1.50	Sand-cast.
60.51 Cu, 36.16 Zn, 0.21 Mn, 0.73 Fe, 1.48 Sn, 0.04 Al	0.96	Sand-cast.
99.01 Cu, 0.07 Fe, 9 Cd	2.76	
50.75 Cu, 0.17 Mn, 48.69 Fe, 0.05 Sn, .02 C	0.99	

\*These values were determined by C. S. Smith (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

\*The miscellaneous alloys were extensively worked, annealed, and slowly cooled except where noted.

COPPER ALLOYS (Cont'd)

Curve	Composition (%)	Remarks	Reference
Fig. 27; Kr. S-Ger. silv.	61 Cu, 20 Zn, 16 Ni	"Neusilber"	J. Kurell and K. Schiffer (1939).
Fig. 27; Kr. Sc-bronze.	46 Cu, 41 Zn, 13 Ni	"Silberbronze"	Do.
Fig. 29a; AL Mn.-Ger. silv.	45.9 Cu, 42.1 Zn, 9.1 Ni, 2.0 Pb, 0.15 Fe, 0.05 Mn.	"German silver"; data file equation $k = 5.3 \times 10^{-4} T$ .	J. F. Allen and E. Mendous (1949).
Fig. 27; Fig. 29a; B.-Ger. silv.	47 Cu, 41 Zn, 9 Ni, 2 Pb.	Mean diameter of crystals was 0.02 mm.	R. Berman (1951b).

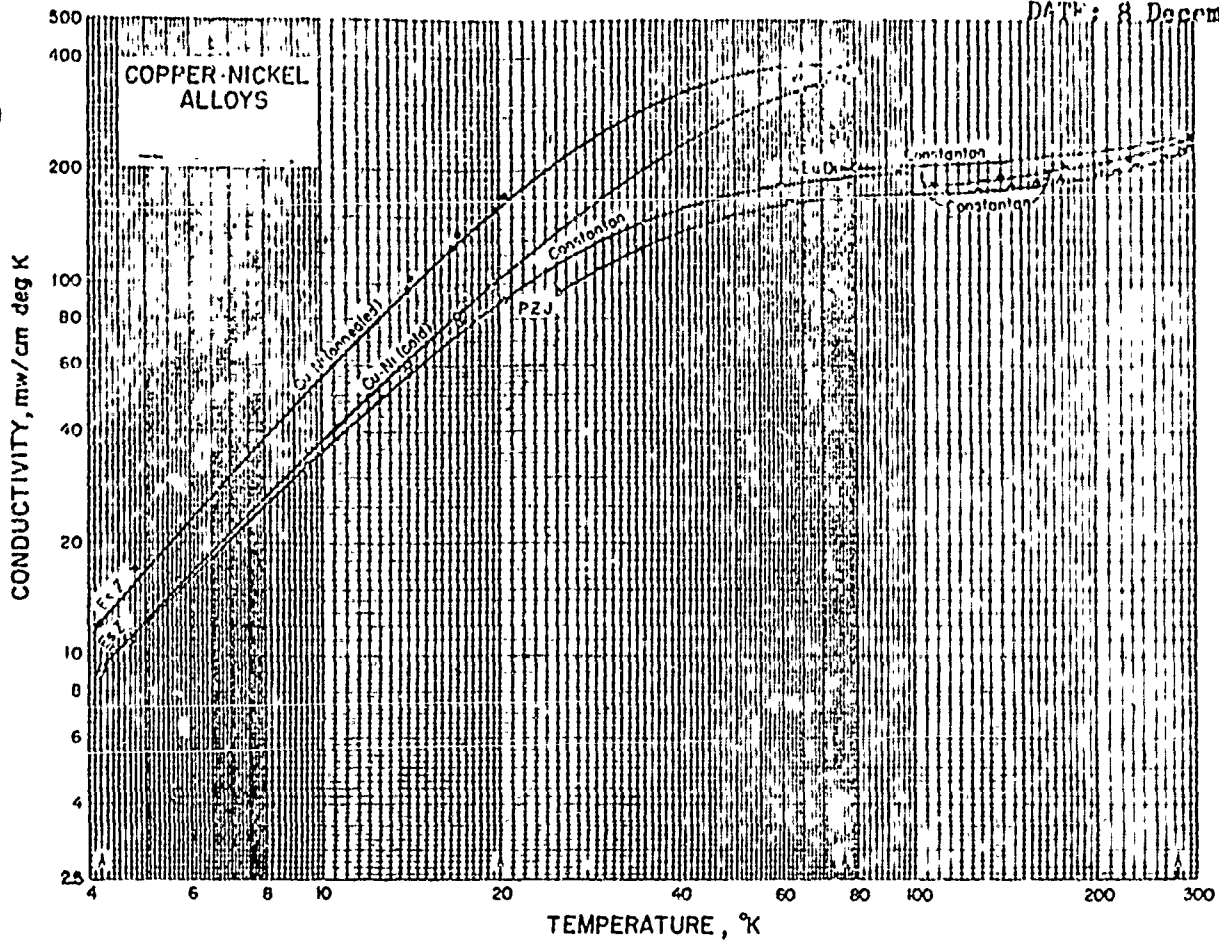
COPPER ALLOYS (Cont'd)  
 COMPANY AND TRADE MANUALS

Name	Nominal Composition (%)	Conductivity
		w/cm deg K
<b>Coppers:</b>		
Electrolytic Tough Pitch	99.92 Cu, 0.01 O <sub>2</sub>	3.91
Deoxidized	99.91 Cu, 0.02 P	3.29
Oxygen-free high cond.	99.92 Cu	3.93
Silver bearing	99.9 Cu, trace Ag	3.93
Anticorrosive phosphorized	99.45 Cu, 0.3 As, 0.03 P	1.76
Free cutting	99.1 Cu, 0.6 Fe	3.65
Hoton deoxidized	99.99 Cu, 0.02 H	3.88
Selenium copper	99.4 Cu, 0.6 Se	3.84
Leaded copper	99.0 Cu, 1.0 Pb	3.81
Chromium copper	99.05 Cu, 0.05 Cr	3.74
Aluminum copper	99.00 Cu, 1.00 Al	3.44
<b>Brasses:</b>		
Gilding	95 Cu, 5 Zn	2.34
Commercial bronze	90 Cu, 10 Zn	1.88
Beating bronze	90 Cu, 9.5 Zn, 0.5 Sn	1.73
Commercial bronze	87.5 Cu, 12.5 Zn	1.73
Red brass	85 Cu, 15 Zn	1.69
Low brass	80 Cu, 20 Zn	1.38
Cartridge brass	70 Cu, 30 Zn	1.21
Yellow brass	65 Cu, 35 Zn	1.17
Muntz metal	60 Cu, 40 Zn	1.21

COPPER ALLOYS (Cont'd)  
 COMPANY AND TRADE MANUALS

Name	Nominal Composition (%)	Conductivity
		w/cm deg K
<b>Leaded Brasses:</b>		
Leaded commercial bronze	90 Cu, 9.5 Zn, 0.5 Pb	1.80
Leaded commercial bronze	89 Cu, 0.25 Zn, 1.75 Pb	1.80
Commercial bronze	90.25 Cu, 8.9 Zn, 1.75 Pb, 1 Ni	1.10
Low leaded brass	61.5 Cu, 35.5 Zn, 0.5 Pb	1.17
Low leaded brass	67 Cu, 32.5 Zn, 0.5 Pb	1.16
Medium leaded brass	61.5 Cu, 34.5 Zn, 1.0 Pb	1.17
High leaded brass	62.5 Cu, 35.75 Zn, 1.75 Pb	1.17
Extra high leaded brass	61 Cu, 34 Zn, 2.0 Pb	1.16
Free cutting brass	62.5 Cu, 35 Zn, 2.5 Pb	1.17
Leaded Muntz metal	61.5 Cu, 35.5 Zn, 3 Pb	1.17
Free cutting Muntz metal	60.5 Cu, 35.5 Zn, 0.5 Pb	1.21
Forging brass	60.5 Cu, 35.4 Zn, 1.1 Pb	1.17
Architectural bronze	60 Cu, 38 Zn, 2 Pb	1.17
Leaded naval brass	57 Cu, 40 Zn, 3 Pb	1.21
Leaded naval brass	60 Cu, 37.5 Zn, 0.7 to 1.75 Pb, 0.75 Sn	1.17
<b>Special Brasses:</b>		
Admiralty metal	87 Cu, 4 Zn, 8 Sn, 1 Pb	0.17
Naval brass	80 Cu, 10 Sn, 10 Pb	0.17
Manganese bronze	61 Cu, 8 Zn, 20 Ni, 4 Pb, 4 Sn	0.23
Aluminum brass	60 Cu, 16 Zn, 16 Ni, 5 Pb, 3 Sn	0.27
"Ambronz-174"	71 Cu, 28 Zn, 1 Sn	1.09
"Ambronz-421"	60 Cu, 39.25 Zn, 0.75 Sn	1.17
Manganese red brass	58.5 Cu, 39 Zn, 1.4 Fe, 1 Sn, 0.1 Mn	1.09
Bluecup red brass	76 Cu, 22 Zn, 2 Al	1.00
Trumpet brass	91.97 Cu, 4.0 Zn, 1.0 Sn, 0.03 P	1.61
Armenian admiralty	88.00 Cu, 10.0 Zn, 2.0 Sn	1.19
Manganese brass	85.0 Cu, 14.0 Zn, 1.0 Mn	0.99
Nickel silver 18%-B	82.0 Cu, 17.0 Zn, 1.0 Sn	0.67
Nickel silver 18%	81.0 Cu, 18.0 Zn, 1.0 Sn	1.21
Leaded nickel silver 12%	71.0 Cu, 28.0 Zn, 1.0 Sn, 0.01 As	1.11
Phosphor bronze 5%-A	70.0 Cu, 29.0 Zn, 1.0 Mn	0.74
Phosphor bronze 10%-D	55 Cu, 27 Zn, 18 Ni	0.29
Phosphor bronze 1.25%-E	68 Cu, 19 Zn, 15 Ni	0.35
Phosphor bronze	65 Cu, 20.7 Zn, 12 Ni, 2 Pb, 0.3 Mn	0.40
Do	56 Cu, 5 Sn, trace P	0.80
Do	92 Cu, 8 Sn, trace P	0.63
Do	90 Cu, 10 Sn, trace P	0.50
Do	89.78 Cu, 1.25 Sn, trace P	2.06
Do	88.7 Cu, 1.25 Sn, 0.05 P	2.18
Do	98.24 Cu, 1.75 Sn, 0.01 P	1.47
Do	95.95 Cu, 4.0 Sn, 0.05 P	0.81
Do	95.75 Cu, 4.0 Sn, 0.25 P	0.81
Do	95.17 Cu, 4.0 Sn, 0.08 P, 0.5 Fe	0.76
Do	91.75 Cu, 5.0 Sn, 0.25 P	0.81
Do	93.9 Cu, 5.0 Sn, 0.1 P, 1 Pb	0.83
Do	93.7 Cu, 6.0 Sn, 0.3 P	0.67
Do	91.75 Cu, 8.0 Sn, 0.25 P	0.62
Do	89.75 Cu, 10.0 Sn, 0.25 P	0.50
Do	87.90 Cu, 10.0 Sn, 4 Zn, 4 Pb, 0.1 P	0.55
<b>Special Bronzes:</b>		
Silicon bronze A	96 Cu, 3.5 Si	0.38
Silicon bronze B	97 Cu, 1.5 Si	0.59
"Everdur-1010"	96.8 Cu, 3.1 Si, 1.1 Mn	0.33
"Everdur-1012"	95.6 Cu, 3.0 Si, 1.0 Mn, 0.4 Pb	0.35
"Everdur-1015"	93.25 Cu, 1.5 Si, 0.25 Mn	0.61
"Everdur-1014"	90.75 Cu, 2.0 Si, 7.25 Al	0.45
5% Aluminum bronze	95 Cu, 5 Al	0.83
10% Aluminum bronze	92 Cu, 8 Al	0.71
Aluminum silicon bronze	88 Cu, 10 Al	0.60
"Calum"	82.5 Cu, 10 Al, 5 Ni, 2.5 Fe	0.38
Chromium copper	91 Cu, 7 Al, 2 Si	0.38
"Hilenco-963"	85.5 Cu, 3.5 Al, 2.0 Sn	0.37
Aluminum bronze 85-1-10	89.05 Cu, 0.85 Cr	3.20
Aluminum bronze 96-4-10	98.6 Cu, 0.9 Cd, 0.6 Sn	3.44
Aluminum bronze	82 Cu, 10 Al, 1 Fe	0.55
	86 Cu, 10 Al, 4 Fe	0.59
	87.5 Cu, 9 Al, 3.5 Fe	0.59

Data from NBS Circular No. 556



**COPPER ALLOYS (Cont'd)**  
**COMPANY AND TRADE MANUALS**

Name	Nominal Composition (%)	Conductivity	State
		w/cm deg K	
Platinum-Copper:			
Platinum-copper.....	97 Cu, 2 Pt, 0.25 Co.....	0.84	Solution treated, quenched.
		1.06	As above plus chemically hardened.
		0.84	As above plus cold-rolled.
		0.78	Solution treated, chemically quenched, cold-rolled.
Platinum alloy 25.....	2 Pt, 0.3 Co, balance Cu...	1.21	
Platinum alloy 185.....	1.7 Pt, 0.3 Co, balance Cu...	1.21	
Platinum alloy 10.....	0.3 Pt, 2.1 Co, balance Cu...	2.28	
Platinum alloy 50.....	0.1 Pt, 1.24 Co, 1.0 Ag, balance Cu...	2.22	
Platinum alloy 20C.....	2.1 Pt, 0.6 Co, balance Cu...	1.06	
Platinum alloy 278C.....	2.7 Pt, 0.6 Co, balance Cu...	0.96	
Platinum alloy 10C.....	0.8 Pt, 2.5 Co, balance Cu...	2.13	

Data from NBS Circular No. 556

**COPPER-NICKEL ALLOYS**

See also the "COPPER ALLOY" graph and tables.

Certs	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
.....	About 82 Cu, 22 Zn, 15 Ni.	"Neusilber"; $k=0.29$ at 0°C.	L. Lorenz (1881).
.....	60 Cu, 40 Ni ..	"Constantan"; $k=0.21$ at 18°C.	W. Jager and H. Dorschner (1900).
.....	54 Cu, 46 Ni ..	$k=0.21$ at 18°C ..	E. Grönlund (1900).
Fig. 37; L-Ger. silv.	62 Cu, 22 Zn, 16 Ni...	"German silver" ..	C. H. Lee (1908).
L-Plat....	Approx. same as above.	"Platinoid" ..	Do.
.....	60 Cu, 40 Ni ..	"Eureka" or constantan; $k=0.21$ at 17°C.	T. Barratt and R. M. Winter (1925).
Fig. 38; Zn. Di-constantan.	60 Cu, 40 Ni ..	61 crystals per cm; also measured samples with other crystal size.	A. Eucken and K. Dittrich (1927).
.....	1 Ni ..	$k=1.50$ at 83°K, 0.63 at 21°K.	E. Grönlund and E. Gjorne (1927).
Fig. 37; Kr. Sc.-Ger. silv.	64 Cu, 16 Ni, 20 Zn..	"Neusilber" ..	J. Karwiel and K. Schäfer (1939).

FIGURE 94

TABLE XLVII

COPPER-NICKEL ALLOYS (Cont'd)

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
Fig. 29a; Al. Min.-Ger. silv.	45.9 Cu, 42.1 Zn, 9.8 Ni, 2.0 Pb, 0.15 Fe, 0.05 Mn.	"German silver"; data fits equation $k = 5.3 \times 10^{-4}$ $T^2$ .	J. F. Allen and E. Mendora (1919).
.....	43 Cu, 20 Ni, 17 Zn.	"Nickel-silver", $k = 25.5$ mW/cm deg. at 10°K, 43.5 at 15°K, 71.1 at 20°K.	K. R. Wilkinson and J. Wilks (1949).
.....	70 Cu, 30 Ni	"Cupro-nickel"; $k = 20.9$ mW/cm deg. at 10°K, 35.6 at 15°K, 50.2 at 20°K.	Do.
Fig. 28; P.Z.J.- constantan.	55 Cu, 45 Ni	.....	R. W. Powers, J. B. Ziegler, and H. L. Johnston (1951c).
Fig. 29a; Hu.-Cu- 20% Ni.	60 Cu, 20 Ni	Also obtained $k = 127$ mW/ cm deg at 21.9°K and 79.9 at 16.3°K.	J. K. Hulm (1951).
Fig. 28; B.- Constantan.	60 Cu, 40 Ni	.....	R. Beriman (1951b).
Figs. 27, 29a; B.-Ger. silv.	47 Cu, 41 Zn, 9 Ni, 2 Pb.	Mean diameter of crystals was 0.02 mm.	Do.
Fig. 27; Es. Zi.-Cu- 10% Ni, annealed.	90 Cu, 10 Ni	Two samples which were annealed, one a single crystal.	I. Estermann and J. E. Zimmermann (1952).
Es. Zi.-Cu- 10% Ni, cold.	.....	Two samples which were cold-worked.	Do.

COPPER-NICKEL ALLOYS (Cont'd)

Composition (%)	Conductivity	State
	w/cm deg K	
99.73 Cu, 0.28 Ni, 0.01 Fe, 0.3 Mg	3.22 ± 0.1	
99.47 Cu, 0.51 Ni, 0.02 Fe, 0.4 Mg	2.92 ± 0.1	
97.94 Cu, 1.97 Ni, 0.02 Fe, 0.4 Mg	1.72 ± 0.1	
94.92 Cu, 4.59 Ni, 0.01 Fe, 0.3 Mg	1.00 ± 0.1	
89.60 Cu, 10.07 Ni, 0.02 Fe, 0.3 Mg, 0.2 C	0.62 ± 0.1	
84.83 Cu, 15.07 Ni, 0.06 Fe, 0.1 Mg, 0.3 Mn.	0.17 ± 0.1	
79.08 Cu, 19.79 Ni, 0.23 Fe, 0.3 Mg	0.16 ± 0.1	
69.61 Cu, 30.33 Ni, 0.03 Fe, 0.5 Mg, 0.13 Mn	0.29 ± 0.1	

Composition (%)	Conductivity	State
	w/cm deg K	
64.14 Cu, 18.33 Ni, 0.19 Fe, 17.04 Zn, 0.3 Mn, 0.2 C	0.33 ± 0.1	
63.17 Cu, 10.89 Ni, 0.14 Fe, 8.22 Zn, 3.31 Sn, 5.4 Pt, 0.23 Mn.	0.28 ± 0.1	Sand-cast.
66.03 Cu, 3.01 Ni, 0.004 Fe, 38.8 Sn	0.76 ± 0.1	Quenched.
96.05 Cu, 3.01 Ni, 0.04 Fe, 38.8 Sn	1.58 ± 0.1	Heated.
96.05 Cu, 3.01 Ni, 0.04 Fe, 38.8 Sn	1.69 ± 0.1	Furnace-cooled.
74.07 Cu, 19.56 Ni, 0.09 Fe, 5.31 Zn	0.39 ± 0.1	
61.5 Cu, 39.44 Ni, 0.07 Fe, 5.69 Zn	0.24 ± 0.1	

\* The values were determined by C. B. Smith, E. W. Palmer (1935) at 20°C. Sometimes the composition percentages add up to more than 100.

\* The copper-nickel alloys were deoxidized with magnesium, cold rolled, and annealed at 500°C.

\* The miscellaneous alloys were extensively worked, annealed, and slowly cooled except where noted.

Data from NBS Circular No. 556

COPPER-NICKEL ALLOYS (Cont'd)  
COMPANY AND TRADE MANUALS

Name	Nominal composition (%)	Conductivity
		w/cm deg K
Cupro-nickel 30%	70 Cu, 30 Ni	0.29
Cupro-nickel 10%	88.5 Cu, 10 Ni, 1.5 Fe	0.47
Nickel-silver 15% A	65 Cu, 18 Ni, 17 Zn	0.33
Nickel-silver 18% B	55 Cu, 18 Ni, 27 Zn	0.25
Nickel-silver 15% C	68 Cu, 15 Ni, 19 Zn	0.35
Constantan	55 Cu, 45 Ni	0.21
Dairy bronze	61 Cu, 20 Ni, 8 Zn, 1 Pb, 1 Sn	0.21
Leaded nickel brass	60 Cu, 16 Ni, 16 Zn, 5 Pb, 3 Sn	0.27
Leaded nickel silver 12%	65 Cu, 12 Ni, 20.7 Zn, 2 Pb, 0.3 Mn	0.10

SILVER ALLOYS

Curve	Composition (%)	Conductivity and remarks	Reference
		w/cm deg K	
.....	90 Ag, 10 Pd	$k = 1.41$ at 25°C	F. A. Schulze (1911).
.....	80 Ag, 20 Pd	$k = 0.51$ at 25°C	Do.
.....	70 Ag, 30 Pd	$k = 0.57$ at 25°C	Do.
.....	60 Ag, 40 Pd	$k = 0.45$ at 25°C	Do.
.....	50 Ag, 50 Pd	$k = 0.32$ at 25°C	Do.
.....	90 Ag, 10 Pt	$k = 0.98$ at 25°C	Do.
.....	75 Ag, 25 Pt	$k = 0.38$ at 25°C	Do.
.....	70 Ag, 30 Pt	$k = 0.31$ at 25°C	Do.
.....	67 Ag, 33 Pt	$k = 0.30$ at 25°C	Do.
Fig. 26; G. Re- Ag-0.4% Au.	99.63 Ag, 0.37 Au	.....	E. Grünisen and H. Reidemann (1931).
G. Re-Ag- 25% Au.	75 Ag, 25 Au	Single crystal	Do.
G. Re-Au 50% Ag.	50 Ag, 50 Au	Single crystal	Do.
Po-Ag Solder.	50 Ag, 15.5 Cu, 16.5 Zn, 16 Cd.	"Easy-Bo"; flame annealed.	R. L. Powell (1951)

GOLD ALLOYS

.....	90 Au, 10 Pd	$k = 0.98$ at 25°C	F. A. Schulze (1911)
.....	80 Au, 20 Pd	$k = 0.59$ at 25°C	Do.
.....	70 Au, 30 Pd	$k = 0.44$ at 25°C	Do.
.....	60 Au, 40 Pd	$k = 0.40$ at 25°C	Do.
.....	50 Au, 50 Pd	$k = 0.36$ at 25°C	Do.
.....	90 Au, 10 Pt	$k = 0.76$ at 25°C	Do.
.....	80 Au, 20 Pt	$k = 0.41$ at 25°C	Do.
.....	70 Au, 30 Pt	$k = 0.30$ at 25°C	Do.
.....	60 Au, 40 Pt	$k = 0.26$ at 25°C	Do.

### GOLD ALLOYS (Cont'd)

Curve	Composition (%)	Conductivity and remarks w/cm deg K	Reference
	92 atomic % Au, 8 atomic % Pt	$k = 0.40$ at $1^\circ\text{C}$	C. H. Johnson and J. O. Lunde (1930).
	81 Au, 19 Pt	$k = 0.13$ at $1^\circ\text{C}$	Do.
	68 Au, 32 Pt	$k = 0.23$ at $1^\circ\text{C}$	Do.
	55 Au, 45 Pt	$k = 0.21$ at $1^\circ\text{C}$	Do.
Fig. 26, G. Re., Au 50%, Ag	50 Au, 50 Ag	Single crystal	E. Gellert and H. Redemann (1931).
G. Re., Au-25, Ag	75 Au, 25 Ag	Single crystal	Do.
G. Re., Au-26, Cu	74.7 Au, 26.1 Cu	Polycrystalline	Do.
G. Re., Au-9, Cu	91 Au, 9 Cu	Polycrystalline	Do.
	50.1 Au, 49.2 Cu	Quenched from $800^\circ\text{C}$ ; $k = 0.193$ at $85^\circ\text{K}$ .	Do.
	do	Same as above except annealed 22 hr at $350^\circ\text{C}$ ; $k = 1.25$ at $85^\circ\text{K}$ .	Do.
	do	Reannealed from $800^\circ\text{C}$ ; $k = 0.23$ at $85^\circ\text{K}$ .	Do.
G. Re., Au-8, Cu	do	Annealed 30 hr at $320^\circ\text{C}$	Do.
G. Re., Au-9, Pd	91.2 Au, 8.8 Pd	Tempered at $800^\circ\text{C}$ for 2 hr.	Do.
	83 Au, 17 Pd	Annealed 2 hr at $800^\circ\text{C}$ ; approx. same curve as "Ag-25, Au".	Do.
	69 Au, 25 Ag, 6 Pt	$k = 0.53$ at room temperature.	Trade Manual.

### ZINC ALLOYS

Trade Designation	Nominal composition (%)	Conductivity w/cm deg K
"Zamak 4"	96 Zn, 4 Al, 0.04 Mg	1.13
"Zamak 5"	95 Zn, 4 Al, 1 Cu, 0.04 Mg	1.09
"Zamak 2"	93 Zn, 4 Al, 3 Cu, 0.04 Mg	1.05
Comm. rolled	99.8 Zn, 0.08 Pb	1.02
Do	99.8 Zn, 0.06 Pb, 0.06 Cd	1.01
Roll-drawn alloy, "Alloy-15"	98.7 Zn, 1 Cu, 0.04 Mg	1.05

### CADMIUM ALLOYS

Curve	Composition (%)	Remarks	Reference
Fig. 29; Eu Ge., Cd-53% Sb	68.7 Cd, 33.3 Sb		A. Eucken and G. Gellert (1912)
Ku. Ge., Cd-50% Sb	50 Cd, 50 Sb		Do.

### MERCURY ALLOYS

Composition (%)	Remarks	Reference
98.8 Hg, 1.19 In	Measured ratio of conductivity in normal and superconducting states. See also the graph and table under "Metallic Elements".	J. K. Hulm (1950)

### TIN ALLOYS

Curve	Composition	Remarks	Reference
Figs. 18a, b	Up to 1% mercury	See Table under Figs. 18a, b, "Metallic Elements".	J. K. Hulm (1950)
Do	Up to 3% indium	do	B. B. Goodman (1953)

### TIN ALLOYS (Cont'd)

#### COMPANY AND TRADE MANUALS

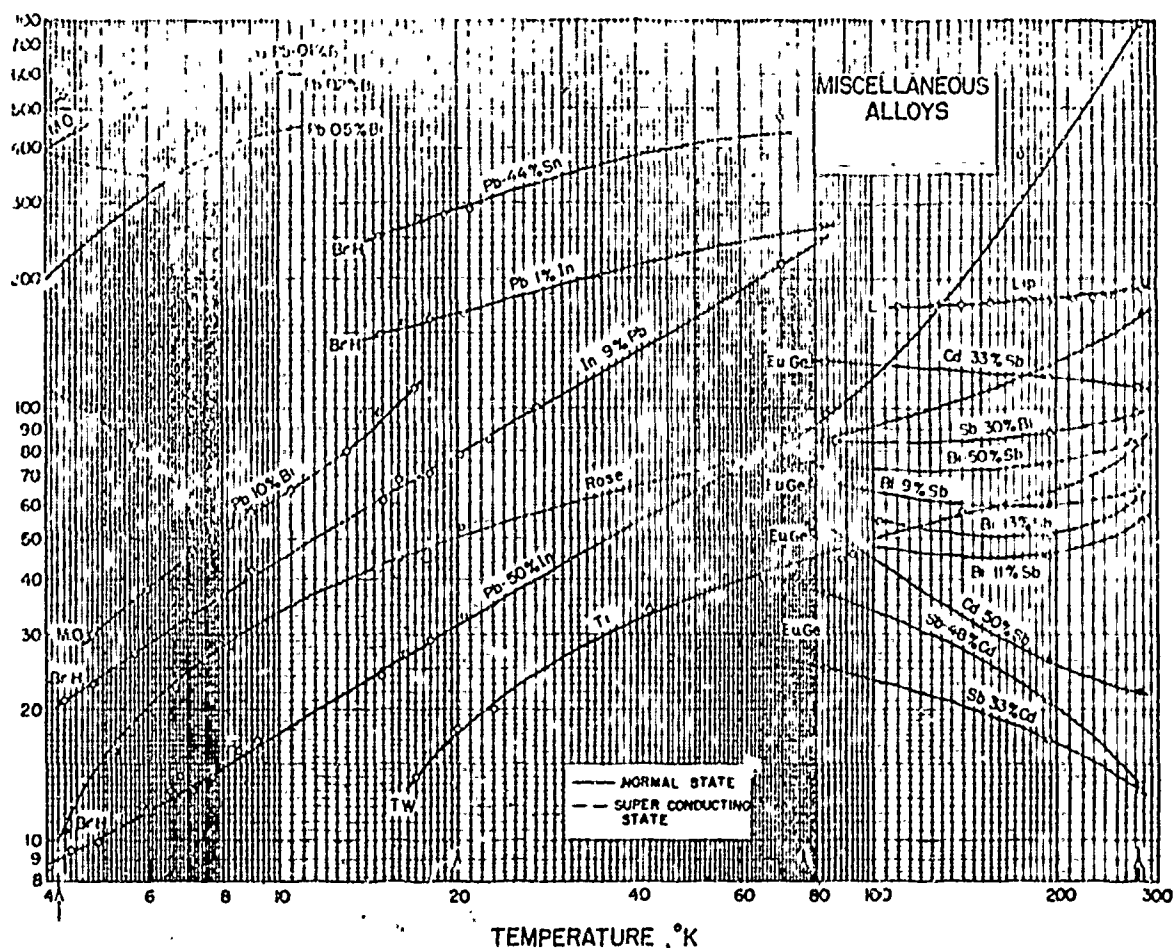
Name	Nominal Composition (%)	Conductivity w/cm deg K
Eutectic soft solder	63 Sn, 37 Pb	0.50
Tin foil	92 Sn, 8 Zn	0.59

### INDIUM, THALLIUM ALLOYS

	66 Tl, 34 Pb	For a sample with "large" crystals, $k = 0.27$ at $273^\circ\text{K}$ ; for a sample with "small" crystals, $k = 0.23$ at $273^\circ\text{K}$ ; 0.11 at $80^\circ\text{K}$ .	A. Eucken and K. Dittich (1927).
	67 Tl, 31 Pb by atomic percent	Measured relative change of thermal conductivity when the alloy became superconductive	W. J. de Haas and H. Bremmer (1932).
Fig. 20, 20a; Br. H., In-9, Pb	91.1 In, 8.6 Pb by atomic percent	Became superconducting at $1.2^\circ\text{K}$ .	H. Bremmer and W. J. de Haas (1936)
Br. H., Pb-50, In	50 In, 50 Pb by atomic percent	Became superconducting at $6.54^\circ\text{K}$	Do.
Fig. 20a, Hg-In-10, 11	60 In, 10.11 Hg by atomic percent	Single crystal; measured both in the normal and superconductive state; transition temperature about $3.1^\circ\text{K}$ .	J. K. Hulm (1952b).

Data from NBS Circular No. 556

TABLE XLVIII



### LEAD ALLOYS

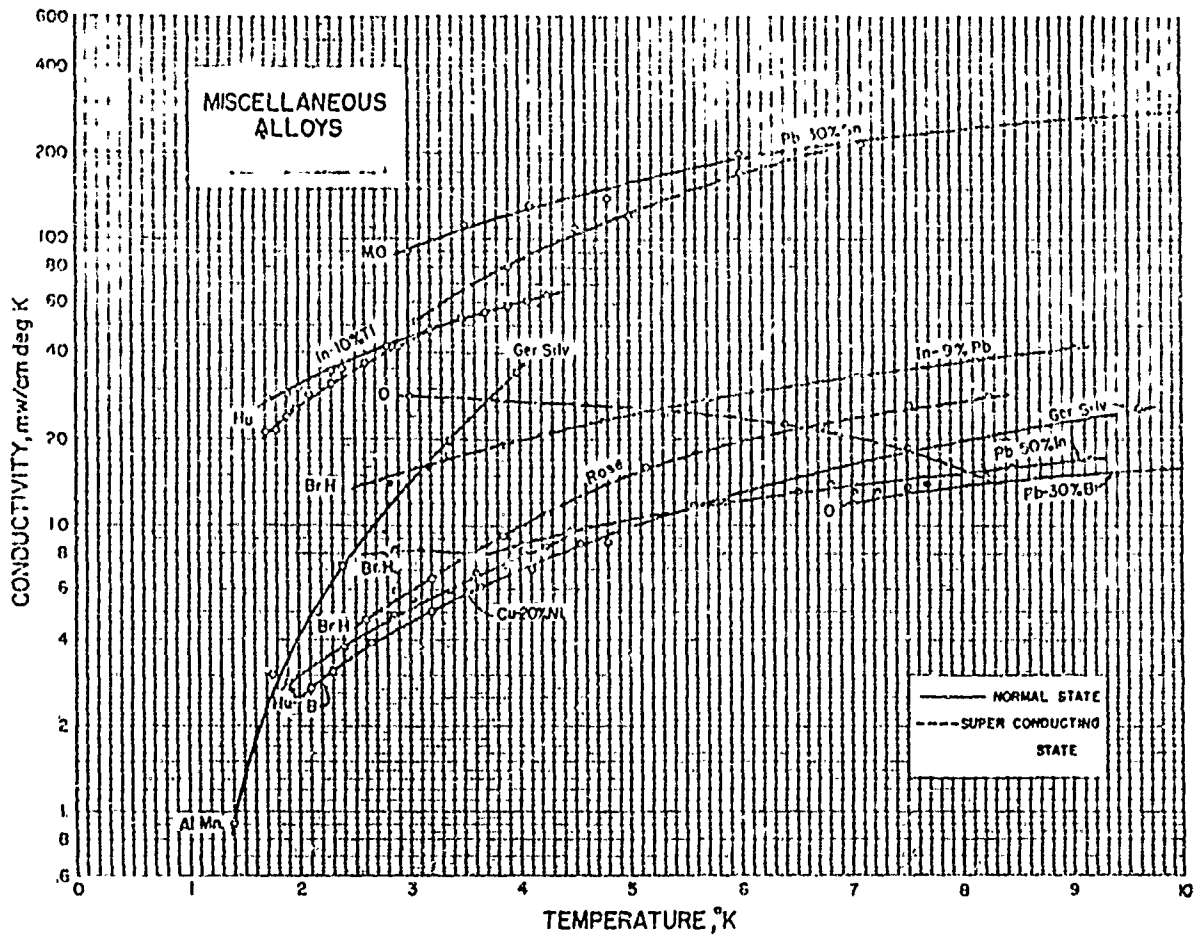
Curve	Composition (%)	Remarks	Reference
Fig. 29: Pb-44% Sn	50 Pb, 44 Sn	Not in solid solution	H. Bremner and W. J. de Haas (1936).
.....	90 Pb, 10 Bi	Measured conductivity in intermediate state and as a function of magnetic field.	K. Mendelsohn and R. B. Fowler (1937).
Fig. 29a; M.O.-Pb-30% Sn	70 Pb, 30 Sn	Measured in normal and superconductive states.	K. Mendelsohn and J. L. Olsen (1936).
Fig. 29: M.O.-Pb-0.1% Bi	99.9 Pb, 0.1 Bi	.....	Do.
M.O.-Pb-10% Bi	90 Pb, 10 Bi	Note that the thermal conductivity in the superconductive state was higher than in the normal state.	Do.
M.O.-Pb-0.2% Bi	99.8 Pb, 0.2 Bi	Measured in normal and superconductive states.	K. Mendelsohn and J. L. Olsen (1936).
M.O.-Pb-0.5% Bi	99.5 Pb, 0.5 Bi	do	Do.
Fig. 29a; O.-Pb-30% Bi	70 Pb, 30 Bi	do	J. L. Olsen (1942).

### LEAD ALLOYS (Cont'd)

Name	Nominal composition (%)	Conductivity w/cm deg K
Corroding lead	99.73 Pb	0.35
1% antimonial lead	99 Pb, 1 Sb	0.33
Hard lead	98 Pb, 4 Sb	0.31
Do.	94 Pb, 6 Sb	0.28
8% antimonial lead	92 Pb, 8 Sb	0.27
Grid metal	91 Pb, 9 Sb	0.27
8-95 soft solder	95 Pb, 5 Sn	0.36
30-70 soft solder	80 Pb, 20 Sn	0.37
60-50 soft solder	60 Pb, 50 Sn	0.46
Lead base babbitt	80 Pb, 15 Sb, 5 Sn	0.24
Do.	75 Pb, 15 Sb, 10 Sn	0.34

Data from NBS Circular No. 556

FIGURE 95



#### BISMUTH ALLOYS

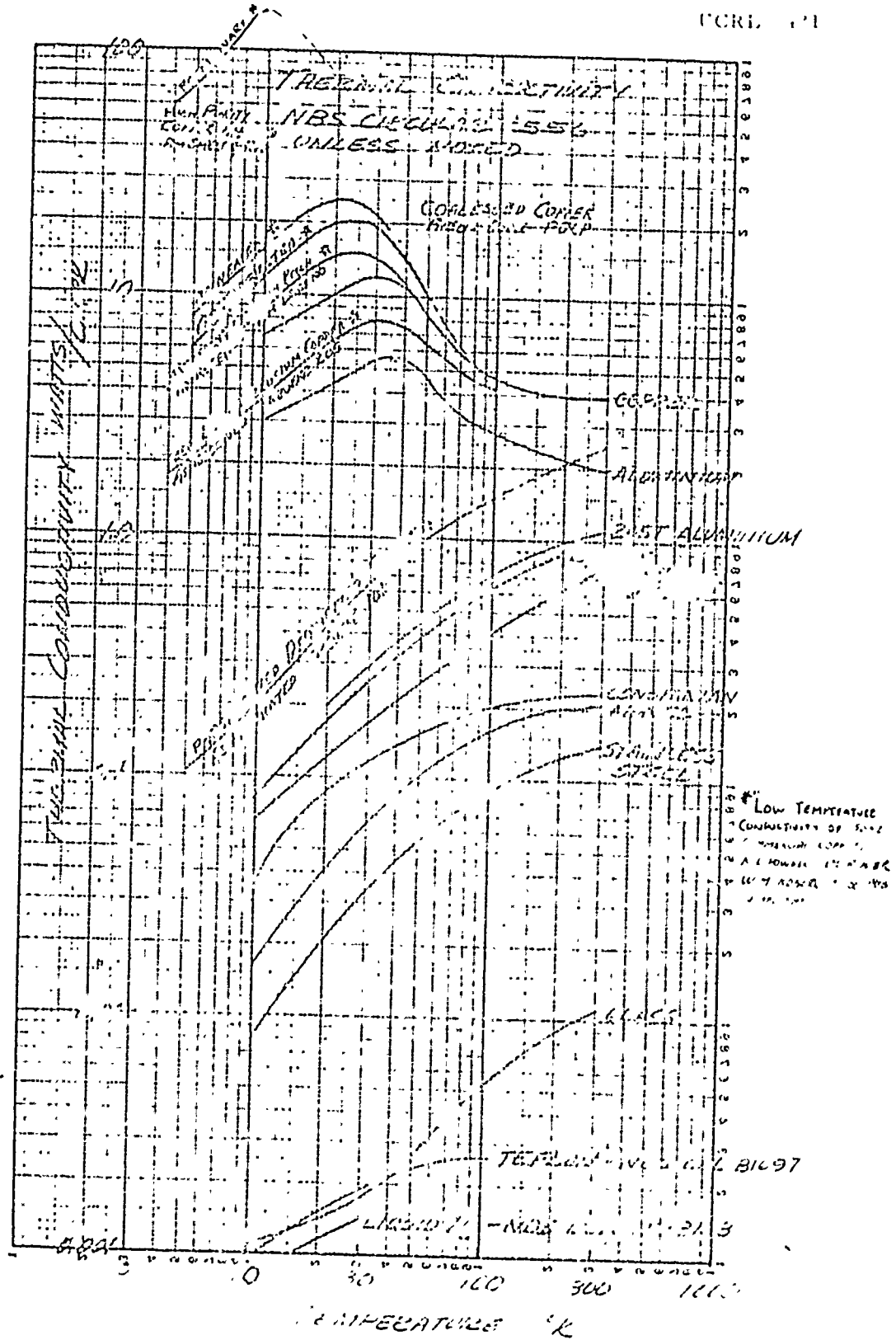
Curve	Composition (%)	Remarks	Reference
Fig. 29; L- Lip.	50 Bi, 25 Pb, 14 Sn, 11 Cd.	"Lapowits alloy".....	C. H. Lenz (1908).
Ge. Ne.-Bi- 50% Sb.	50 Bi, 50 Sb.....		G. Gehlhoff and F. Neumeier (1913).
Ge. Ne.-Bi- 20% Sb.	80 Bi, 70 Sb.....		Do.
Ge. Ne.-Bi- 13% Sb.	87 Bi, 13 Sb.....		Do.
Ge. Ne.-Bi- 11% Sb.	89 Bi, 11 Sb.....		Do.
Ge. Ne.-Bi- 9% Sb.	91 Bi, 9 Sb.....		Do.
Fig. 29, 29a; Dr. H.- Rose.	50 Bi, 25 Pb, 14 Sn..	"Rose's metal".....	H. Bremner and W. J. de Haas (1934).

#### ANTIMONY ALLOYS

Curve	Composition (%)	Remarks	Reference
Fig. 29; Eu. (Ge.-Cd- 50% Pb.	50 Sb, 50 Cd.....		A. Encken and G. Gehlhoff (1912).
Eu. Ge.-Sb- 48% Cd.	51.7 Sb, 48.3 Cd.....		Do.
Eu. Ge.-Sb- 33% Cd.	66.7 Sb, 33.3 Cd.....	"Very hard".....	Do.
Ge. Ne.-Sb- 30% Bi.	70 Sb, 30 Bi.....		G. Gehlhoff and F. Neumeier (1913a).
Ge. Ne.-Bi- 50% Sb.	50 Sb, 50 Bi.....		Do.

Data from NBS Circular No. 556

FIGURE 96



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 Model 7  
 DATE: 8 Dec. 1962

Data from: 50-10 Company  
 Engineering Laboratory  
 100-100, New York  
 July 1, 1963

TABLE XLIX  
THERMAL CONDUCTIVITY OF VARIOUS INSULATIONS

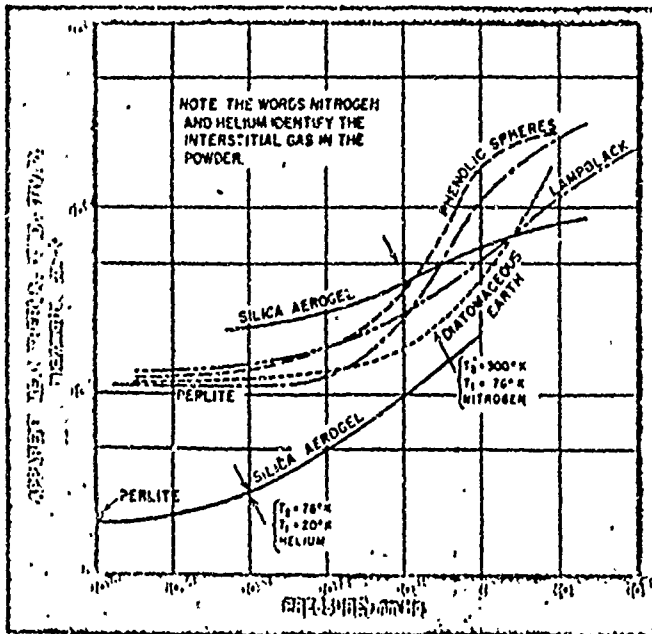
<u>Insulation</u>	<u>Thermal Conductivity Between Room Temperature and 90°K Btu/hr.-ft.-°F</u>	<u>Thermal Conductivity Between Room Temperature and 20°K Btu/hr.-ft.-°F</u>	<u>DENSITY lb./ft.<sup>3</sup></u>
Bantocel "A"	$1400 \times 10^{-5} (1)$	-	-
Bantocel "A"	$120 \times 10^{-5}$	$96.0 \times 10^{-5}$	10
Perlite	$90 \times 10^{-5}$	$72.0 \times 10^{-5}$	10
Straight Vacuum	$78 \times 10^{-5} (2)$	$62.0 \times 10^{-5}$	11
Minie CS-5	$22 \times 10^{-5}$	$17.6 \times 10^{-5}$	7
Minie SI-4	$3 \times 10^{-5}$	$2.5 \times 10^{-5}$	3
Minie SI-12	$10 \times 10^{-5}$	-	-

(1)  $P = 14.7$  psia and  $T = 0^\circ\text{C}$ . All other values are at high vacuum.

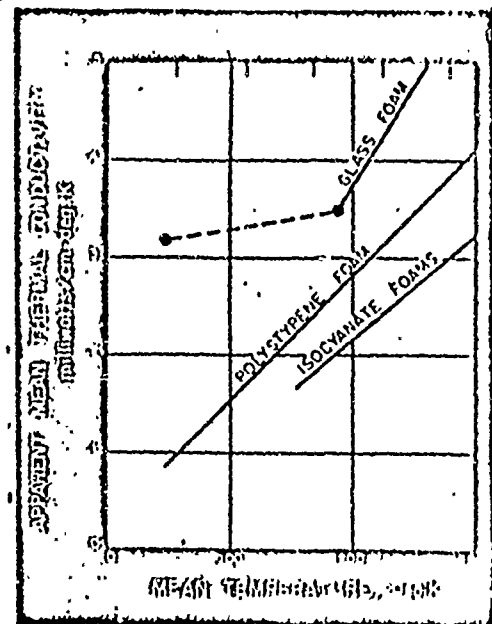
(2) Lowest Conductivity for 1 In. Space between faces.

FIGURE 98

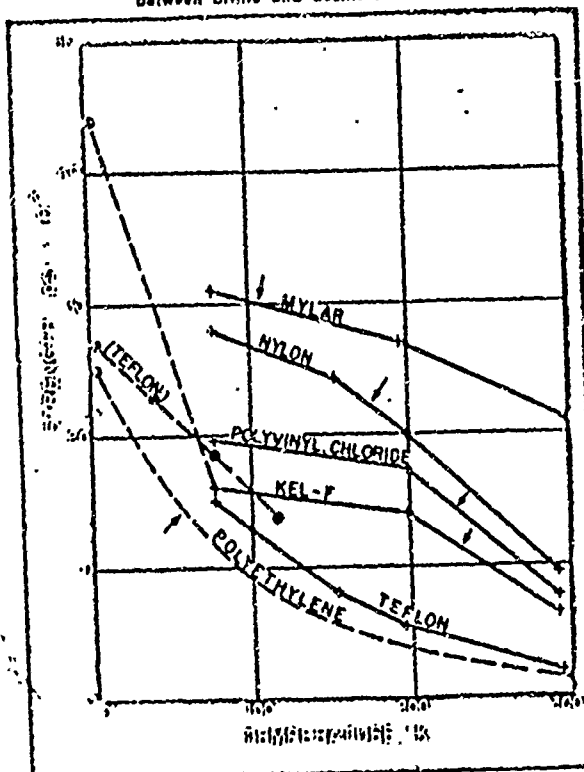
Apparent mean thermal conductivities of some powders. ( $T_1$  and  $T_2$  are the respective boundary temperatures.)



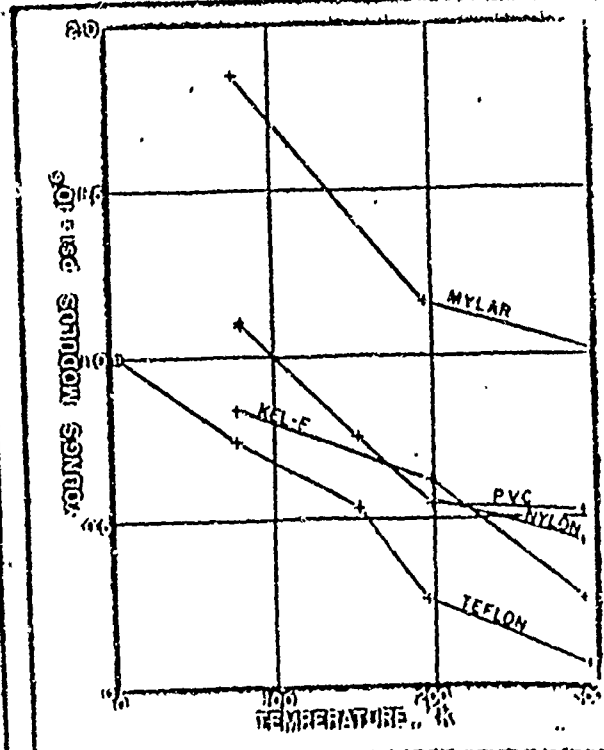
Apparent mean thermal conductivities of some closed-cell foams.



Strength of plastics. (+ = Tensile strength; ⊖ = Compressive yield strength). Arrows locate approximate boundaries between brittle and ductile failure.



Young's modulus of plastics. (+ = Tensile; ⊖ = Compressive)



Data from Cerrucini, Chem. Eng. Prog. 53, p. 262

TABLE L

Specific Heats of Some Selected Substances  
C<sub>p</sub>, cal/(g)(°K.)

Temperature, °K.	Al (2)	Mg (2)	Cu (2)	Ni (2)	n-Mn (1)	α-Fe (2)	γ-Fe (12)	Cr (2)	18 Cr 8 Ni Stainless* (2)	Monel** (1)	Fused Silica (1) Pyrex*** (1)	Teflon (11)
20	.0024	.0011	.0019	.0012	.0025	.0011	.0014	.0096	.0011	.0014	.006	.0055
(H <sub>2</sub> , b.p.)	.0037	.0050	.0235	.016	.0211	.1129	.0210	.0090	.016	.0186	.0272	.0264
50												
77												
(H <sub>2</sub> , b.p.)	.0015	.011	.0171	.0322	.0473	.0343	.0487	.0257	.030	.0417	.0470	.047
90												
(O <sub>2</sub> , b.p.)	.102	.141	.0554	.0136	.0577	.0141	.0604	.0585	.050	.0509	.0570	.0575
160	.116	.155	.0507	.0155	.0641	.0516	.0634	.059	.057	.0571	.0643	.065
150	.164	.202	.0774	.0735	.0672	.0775	.0975	.0757	.083	.0782	.0982	.101
200	.191	.221	.0854	.0913	.1003	.0918	.1118	.0925	.099	.0897	.129	.132
298	.215	.235	.0924	.1060	.1146	.1070	.1251	.1073	.114	.1019	.177	.182

\* Calculated on basis 18 Cr 8 Ni balance γ-Fe, then adjusted for agreement with experimental values near room temperature.

\*\* Calculated.

\*\*\* Calculated from data for SiO<sub>2</sub> and B<sub>2</sub>O<sub>3</sub>.

Mean Linear Thermal Expansion of Various Solids  
10<sup>-6</sup>Δl/l.

°K.	Cu	Ni	Al	Mg	Zn	Ti	1020 low Carbon Steel	304 Stainless Steel	Monel	Inconel	Free-machining Yellow Brass	Pyrex	Araldite 501	Teflon
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	1	1	0	0	-1.1	0	0	0	-1	10	30
40	2	1	2	5	9	1	1	-1.5	1.5	1	4	-2	39	90
60	10	4	10	12	28	2	4	+2.8	6	5	13	-1.5	78	160
80	25	12	24	29	57	6	10	14	15	12	34	+1	126	245
100	44	23	46	55	93	14	20	30	29	24	57	4.5	181	335
120	67	38	72	87	133	24	32	50	45	38	85	8.5	242	430
140	92	55	104	124	176	35	47	73	64	55	115	13	310	540
160	119	74	138	164	221	47	63	97	85	74	146	17.5	385	660
180	148	95	175	208	267	60	81	124	107	95	180	22.5	467	805
200	178	117	214	254	314	74	101	151	130	117	214	27.5	556	995
220	209	140	255	303	363	89	121	180	155	140	249	33	651	1,215
240	240	164	297	353	415	105	142	210	180	163	285	39	753	1,440
260	272	188	341	403	465	121	164	241	207	187	322	44.5	862	1,670
280	305	213	385	453	518	138	187	272	234	212	359	50.5	980	1,900
300	339	239	431	503	572	155	210	304	261	238	397	57	1,107	2,460

Mechanical Properties of Plastics

Selected Minimum Total Emissivities\*

Surface	Temp., °K.	4	20	77	300
Copper	0.0050	0.008	0.018		
Gold		.01	.02		
Silver	.0044	.008	.02		
Aluminum	.011	.018	.03		
Magnesium		.07			
Chromium		.08	.08		
Nickel		.022	.04		
Rhodium		.078			
Lead	.012	.036	.05		
Tin	.012	.013	.05		
Zinc		.026	.05		
Brass	.018		.035		
Stainless Steel, 18-8		.048	.08		
50 Pb 50 Sn solder		.032			
Glass, paints, carbon					>.9
Silver plate on copper	.013	.017			
Nickel plate on copper	.027	.033			

\* Actually absorptivities for radiation characteristic of 300°K. Normal and hemispherical values are included indiscriminately.

	T	Tensile strength lb./sq.in. × 10 <sup>-3</sup>	Compressive yield strength* lb./sq.in. × 10 <sup>-3</sup>	Young's modulus lb./sq.in. × 10 <sup>-3</sup>
	°K.			
Teflon (Polytetrafluoroethylene)	295	2.	....	.06
	195	5.5	....	.26
	153	8.	9.	.54
	77	15.	18.5	.74
	20	....	25.	....
	4	....	27.	1.0*
Kel-F (Polytrifluoromonoethylethylene)	293	6.3	....	.26
	198	14.0	....	.62
	77	16.2	....	.84
	4	....	44.	....
Polyethylene	300	1.3	....	.02
	4	....	25.	....
Polyvinylchloride	293	7.7	....	.52
	198	17.4	....	.55
	77	19.7	....	1.11
	293	9.5	....	.43
Nylon	198	20.1	....	.56
	153	24.3	....	.75
	77	27.9	....	1.10
Mylar (Polyethyleneterephthalate)	300	21.0	....	1.01
	193	27.	....	1.16
	77	31.	....	1.85

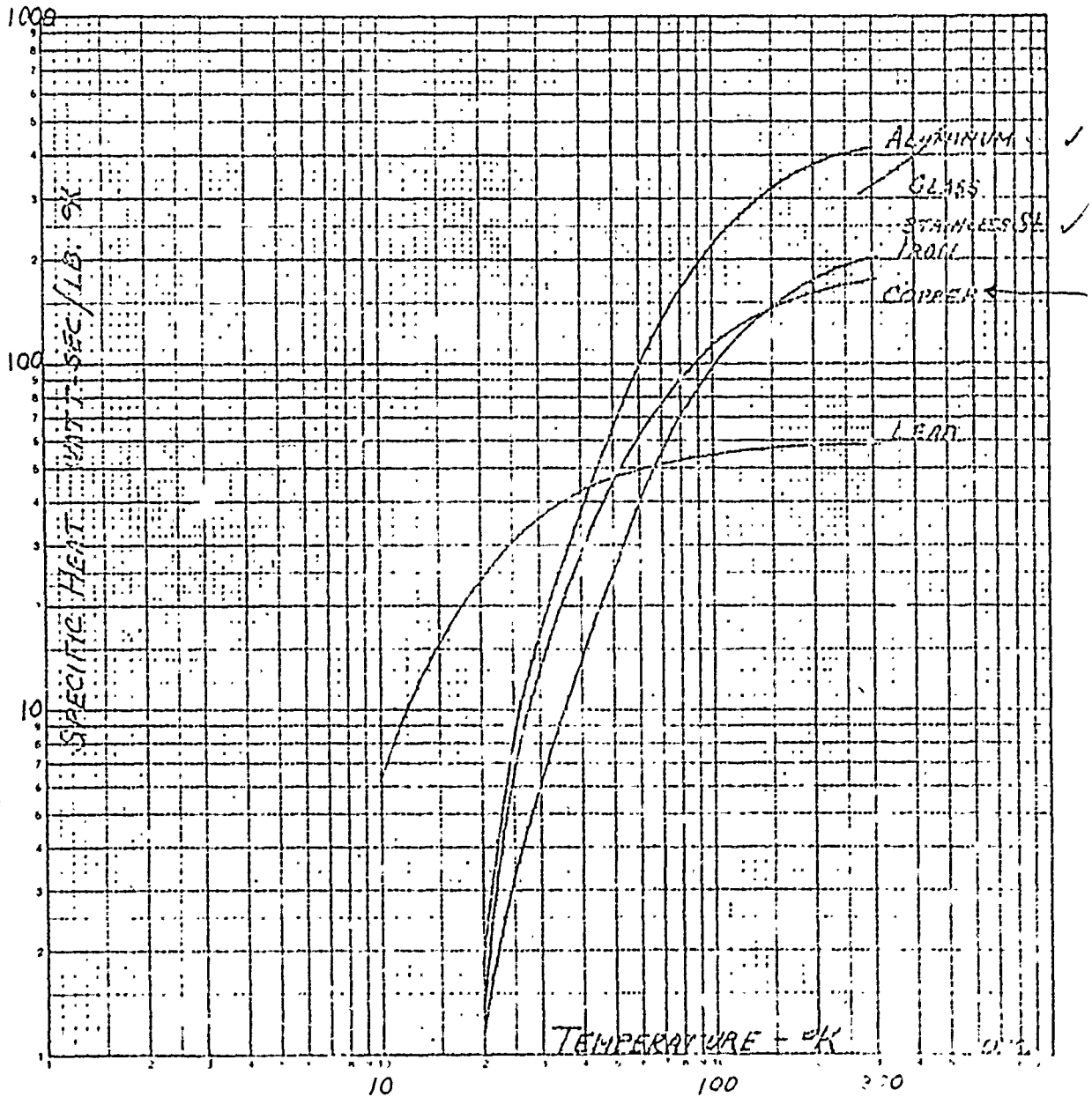
\* Compression data by Swenson (40). All other values were measured in tension and are from (41) and (42).

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INT  
C<sub>p</sub> of Elements, Gen Electric

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## SPECIFIC HEAT

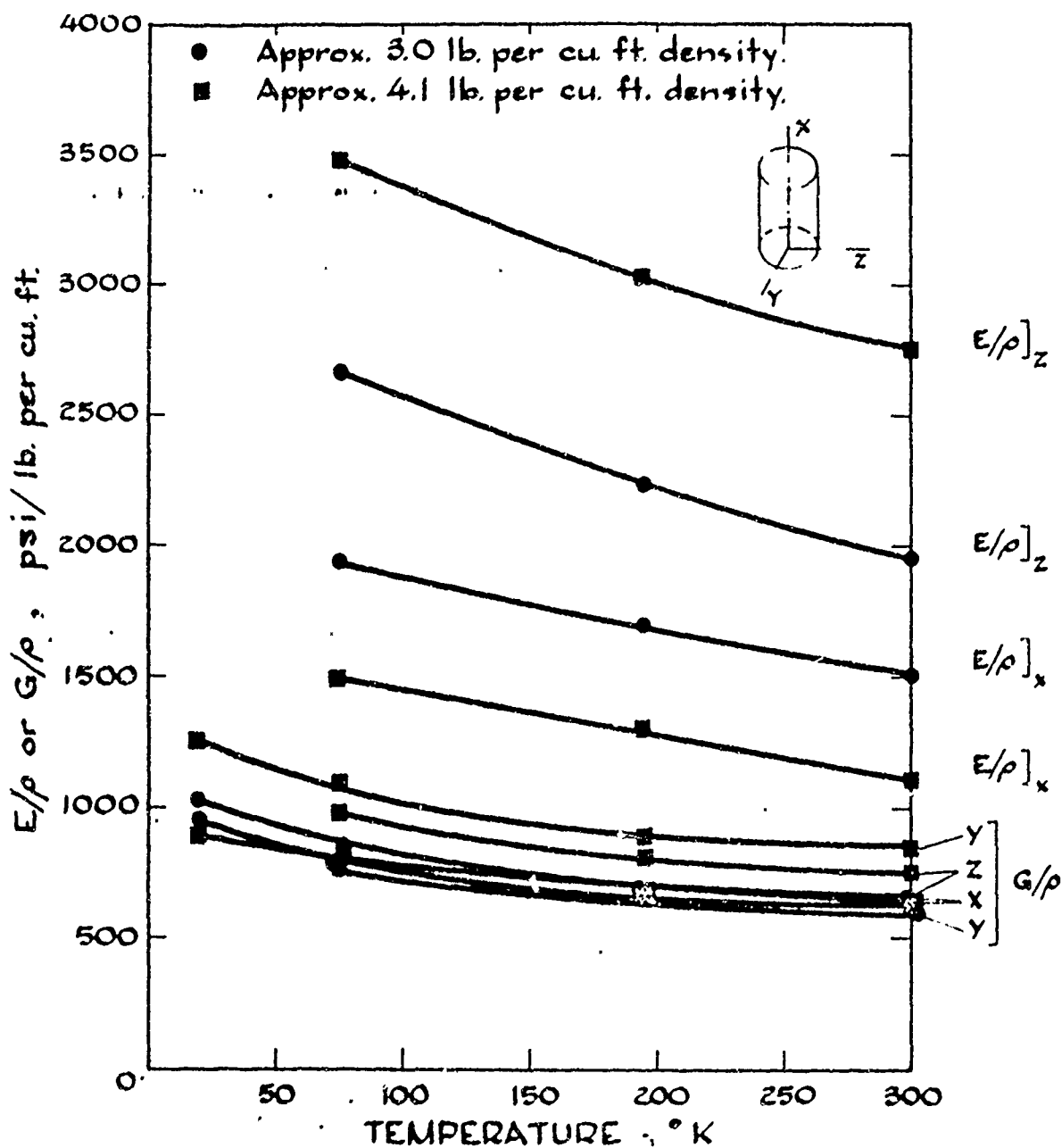
DATA: INT CRITICAL TABLES, VOL V-P85  
C<sub>p</sub> OF ELEMENTS, GEN ELECTRO



**TABLE L1**  
**ELASTIC PROPERTIES OF EXPANDED POLYSTYRENE**  
**FROM 9 SPECIMENS OF APPROXIMATELY**  
**1.0 LB. PER CU.FT. DENSITY**

Property psi/lb. per cu. ft.	Temperature °K	Direction			Z/X
		X	Y	Z	
E/p	300	1520	~1772	1955	1.30
E/p	195	1689	-	2228	1.31
E/p	76	1944	-	2657	1.36
G/p	300	610	~ 600	667	1.09
G/p	195	650	-	698	1.08
G/p	76	781	~ 757	850	1.09
G/p	20	756	-	1031	1.08

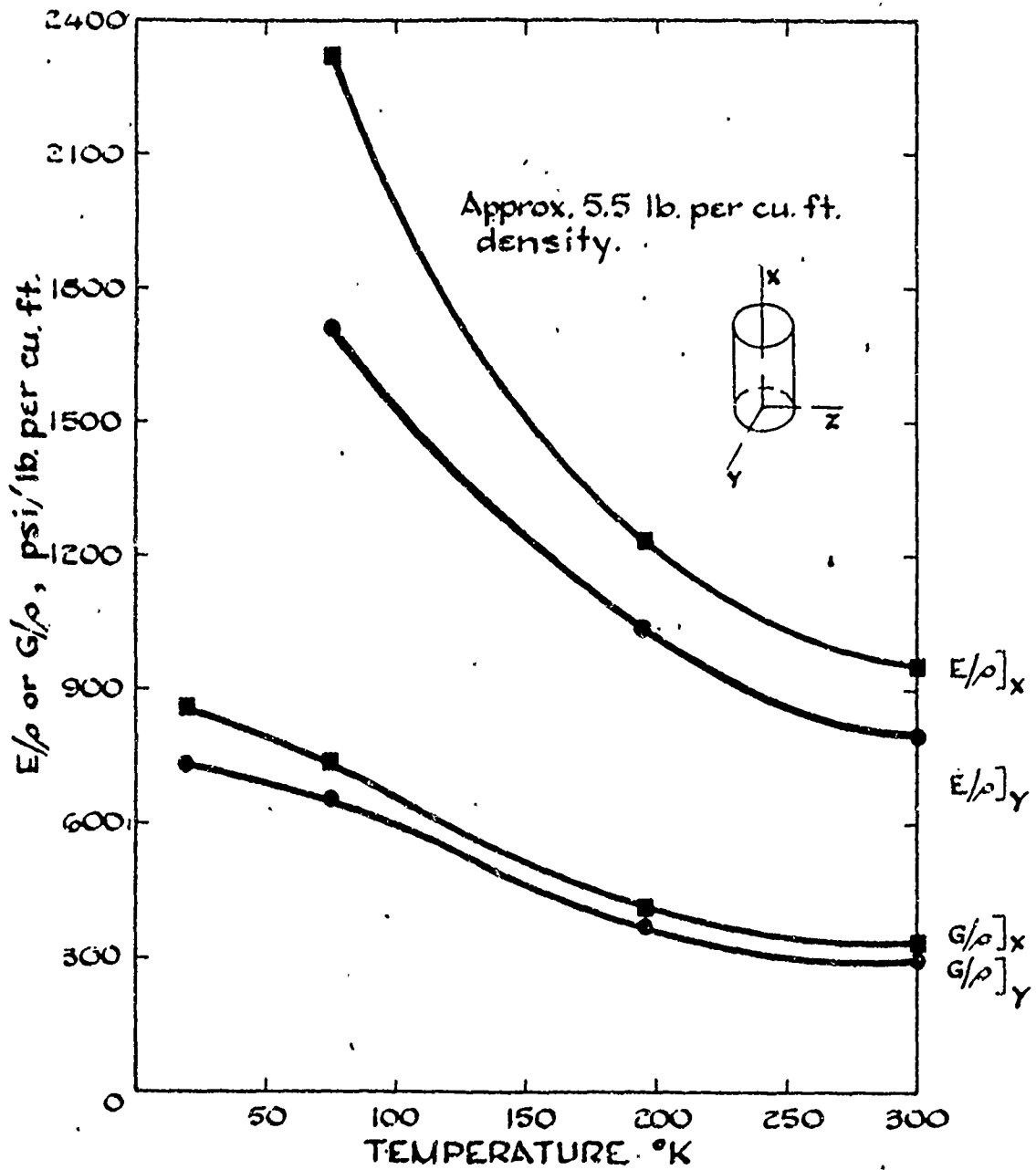
DATA FROM NBS, R. M. McCLINTOCK



# $E/\rho$ AND $G/\rho$ FOR EXPANDED POLYSTYRENE

Figure 100

DATA FROM: NBS, R. M. McClintock



# $E/\rho$ AND $G/\rho$ FOR EXPANDED EPOXY RESIN

Figure 101

Data from NBS, R. M. McClintock

TABLE III

Coefficients of Linear Expansion of Stainless Steels in Range -300° to 1000°F  
 Mean Coefficients  $\times 10^6$  per °F

Ma- terial Type No.	Melt or Stock No.	-300° to 70°F	-100° to 70°F	0° to 70°F	70° to 200°F	70° to 300°F	70° to 400°F	70° to 500°F	70° to 600°F	70° to 700°F	70° to 800°F	70° to 900°F	70° to 1000°F
301	T18131	7.6	7.3	8.7	9.2	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1
304	022396	7.4	7.7	8.2	8.5	8.0	8.2	8.4	8.5	8.7	8.8	8.9	9.0
316	022398	7.1	7.4	7.8	8.0	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
347	022397	7.5	8.1	8.5	8.7	8.2	8.4	8.5	8.6	8.7	8.8	8.9	9.0
310	022357	7.0	7.5	8.0	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.1	9.2
330	022356	8.8	6.5	7.3	8.1	8.3	8.5	8.7	8.9	9.0	9.1	9.2	9.4

Instantaneous Coefficients  $\times 10^6$  Per °F

Ma- terial Type No.	Melt or Stock No.	-300°F	-200°F	-100°F	0°F	100°F	200°F	300°F	400°F	500°F	600°F	700°F	800°F	900°F	1000°F	Taken During Cooling from 700°F		
																0°F	-100°F	-300°F
301	T18131	5.3	6.8	7.4	8.3	8.9	9.2	9.7	9.8	10.1	10.3	10.4	10.6	10.8	10.8			
304	022396	5.8	6.7	7.2	7.8	8.7	9.0	9.4	9.7	9.9	10.1	10.4	10.7	10.8	10.8			
316	022398	5.6	6.3	6.8	7.6	8.5	9.1	9.4	9.7	9.9	10.2	10.3	10.5	10.6	10.6			
347	022397	5.2	6.4	7.1	8.3	8.8	9.2	9.7	9.9	10.1	10.4	10.6	10.8	10.9	10.9			
310	022357	4.9	5.9	7.1	7.7	8.2	8.5	8.9	9.3	9.4	9.6	9.8	10.0	10.2	10.3			
330	022356	3.1	4.7	5.9	7.1	7.3	8.3	8.7	9.1	9.3	9.6	9.8	10.0	10.2	10.4			

Data from International Nickel Company.

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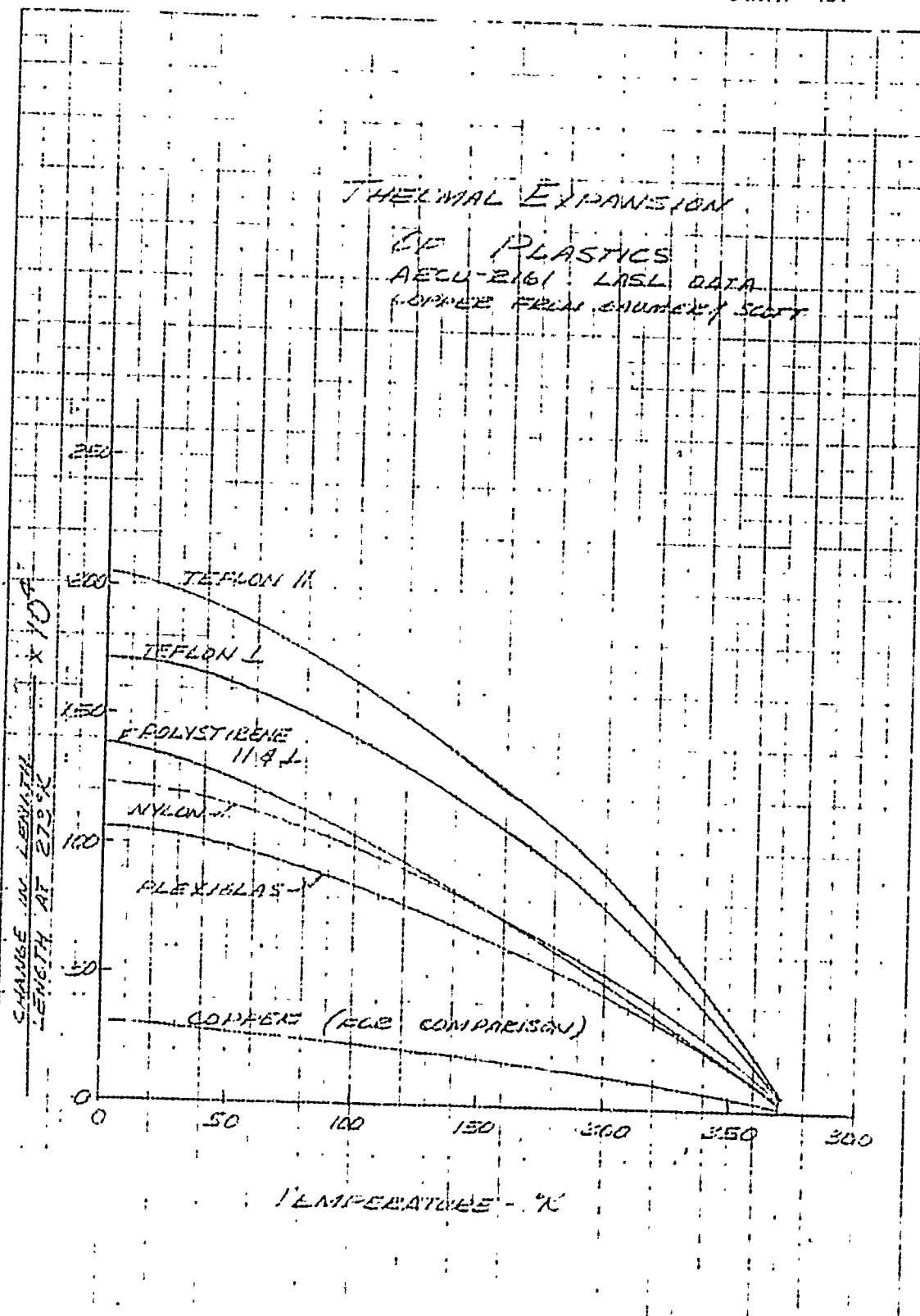


FIGURE 102

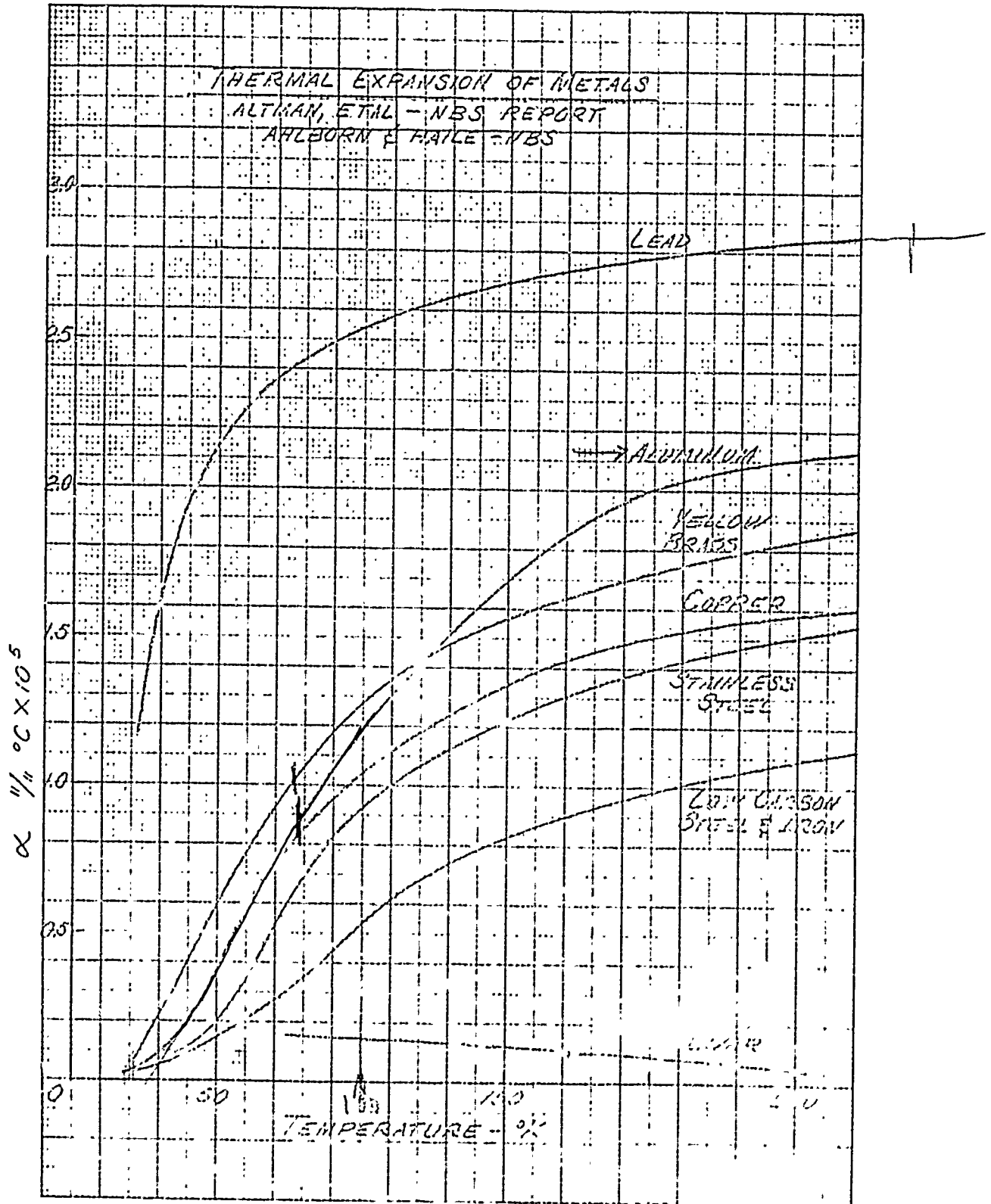


TABLE LIII

THERMAL EXPANSION DATA ON VARIOUS  
AIRCRAFT ALLOYS OVER THE RANGE FROM  
ROOM TEMPERATURE TO  $-253^{\circ}\text{C}$  ( $20.5^{\circ}\text{K}$ )

T ( $^{\circ}\text{K}$ )	$\Delta L/^{\circ}\text{K}$	Coeff. of Exp. (Inches/Inch/ $^{\circ}\text{K}$ )
<u>8630 Steel</u>		
290		
250	$75.0 \times 10^{-6}$	$25.0 \times 10^{-6}$
200	58.0	19.3
150	32.0	10.7
100	14.0	4.7
50	2.0	.7
20.5	.85	.3
<u>248-T4 Aluminum</u> ←		
290		
250	70.0	23.3
200	72.0	24.0
150	60.0	20.0
100	46.0	15.3
50	16.0	5.3
20.5	3.4	1.1
<u>758-T6 Aluminum</u>		
290	10.0	
250	12.0	
200	6.0	
150	80.0	26.7
100	76.0	25.3
50	66.0	22.0
20.5	40.0	13.3
	12.0	4.0
	6.8	2.3

$$E = 11.6 \times 10^4$$

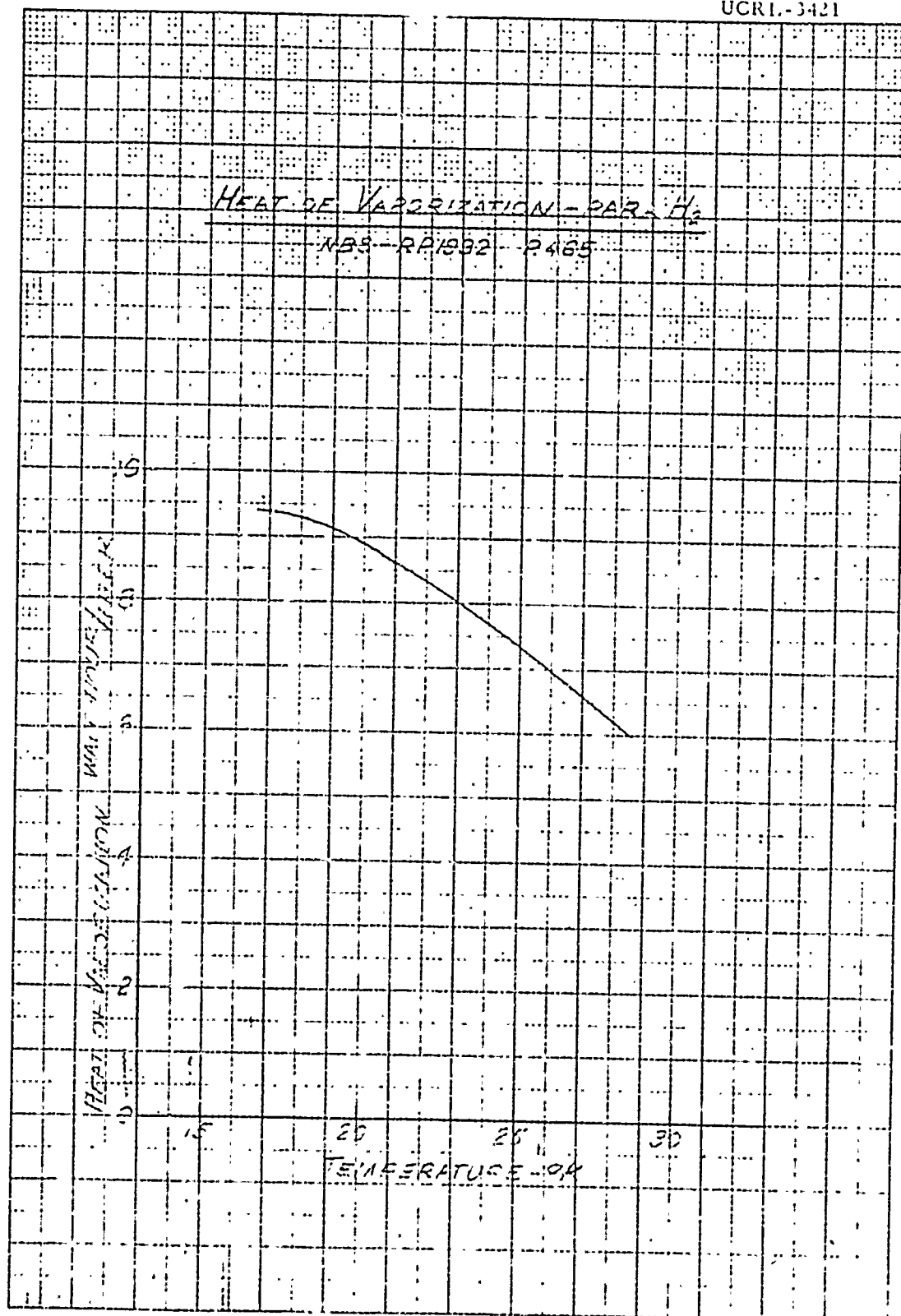
$$\alpha = 0.32$$

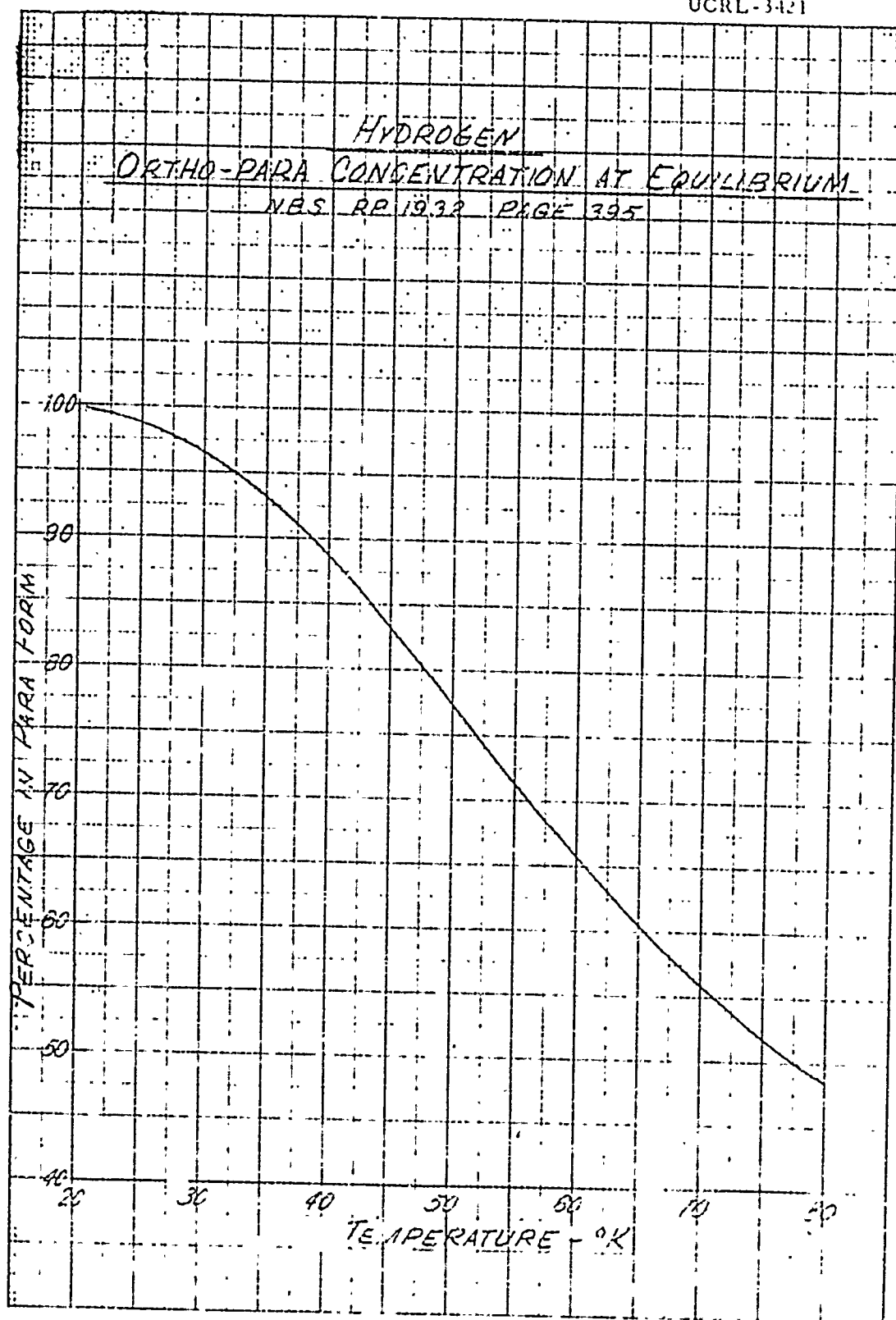
TABLE LIII  
 (Continued)

T (°K)	$\Delta L/^\circ K$	Coeff. of Exp. (Inches/Inch/°K)
<u>304 Stainless Steel</u>		
290		
250	$50.0 \times 10^{-6}$	$16.7 \times 10^{-6}$
200	47.0	15.7
150	34.0	11.3
100	16.0	5.3
50	7.0	2.3
20.5	3.4	1.1
<u>Wrought Titanium</u>		
290		
250	$30.0 \times 10^{-6}$	$10.0 \times 10^{-6}$
200	28.0	9.3
150	20.0	6.7
100	12.0	4.0
50	6.0	2.0
20.5	1.7	.6

HEAT OF VAPORIZATION - PAR.  $H_2$ 

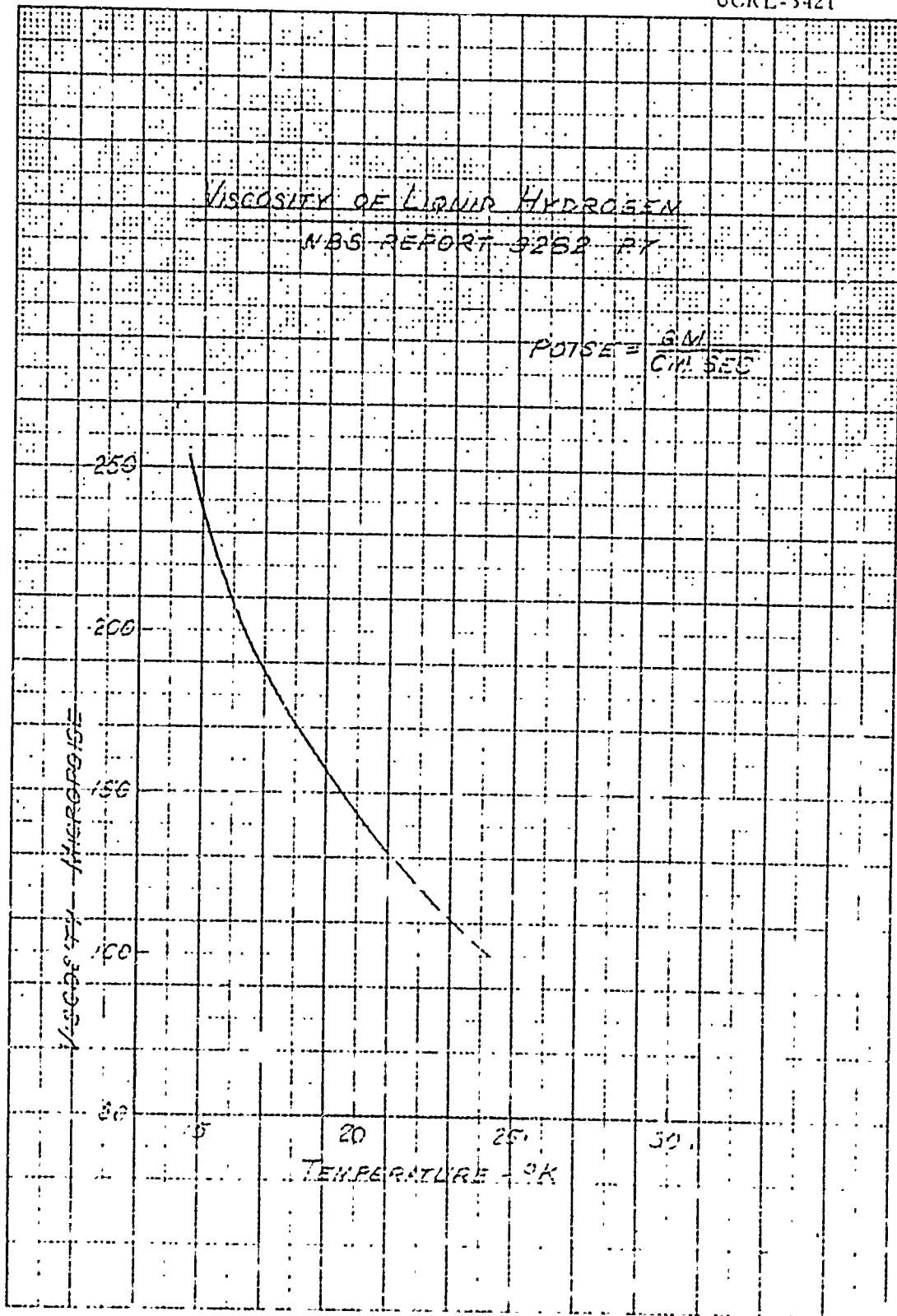
NBS-RA1992 2465





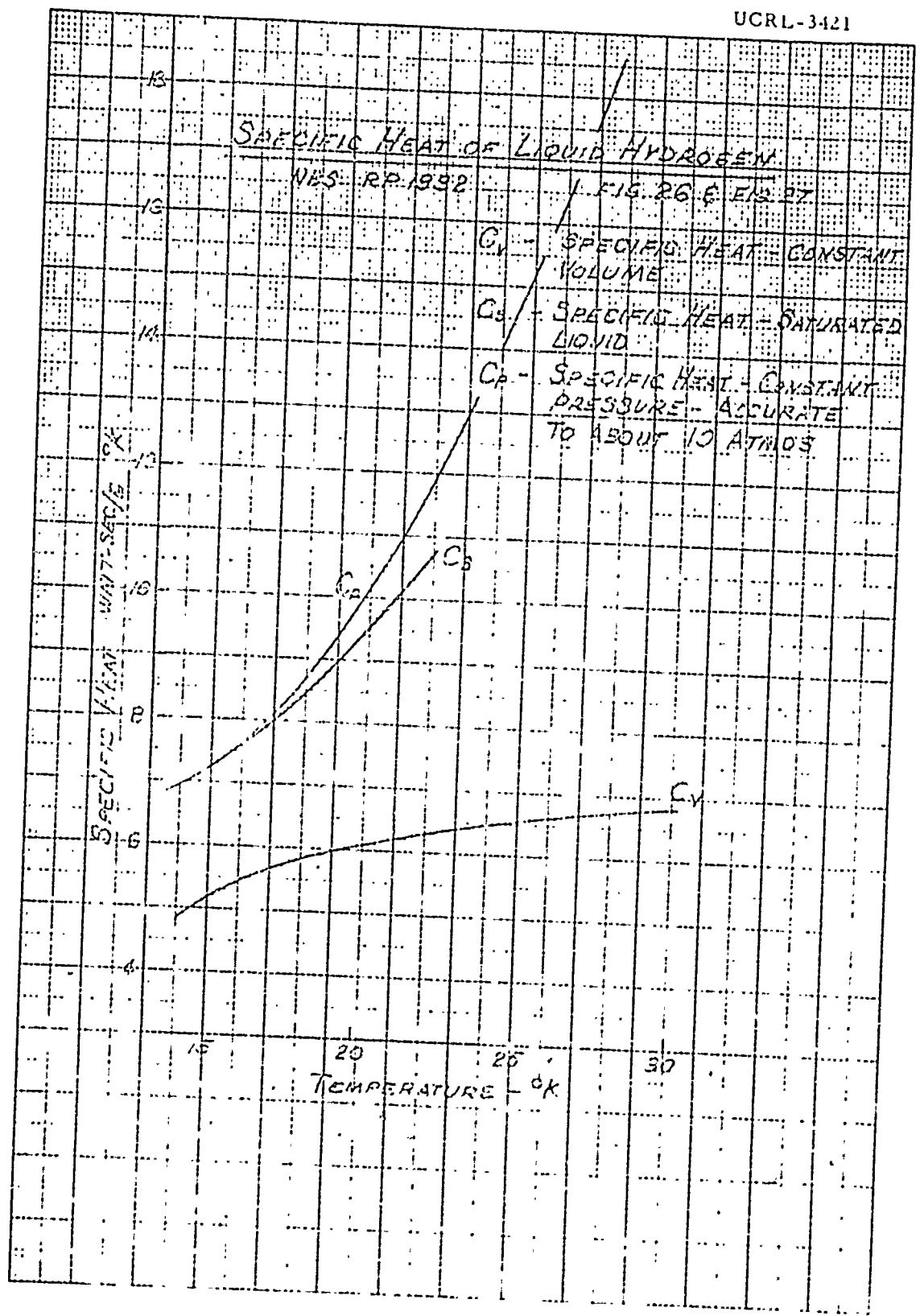
VISCOSITY OF LIQUID HYDROGEN  
NBS REPORT 3252 PT

$$\text{POISE} = \frac{\text{G.M.}}{\text{CM. SEC}}$$



Page 1 of 1  
 FM 10  
 May 1957  
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SURFACE TENSION OF LIQUID HYDROGEN

NBS REPORT 3282-413

$$\text{SURFACE TENSION} = 5.83 - 0.18T \text{ DYNES/CM}$$

SURFACE TENSION - DYNES/CM

2.0

1.0

0

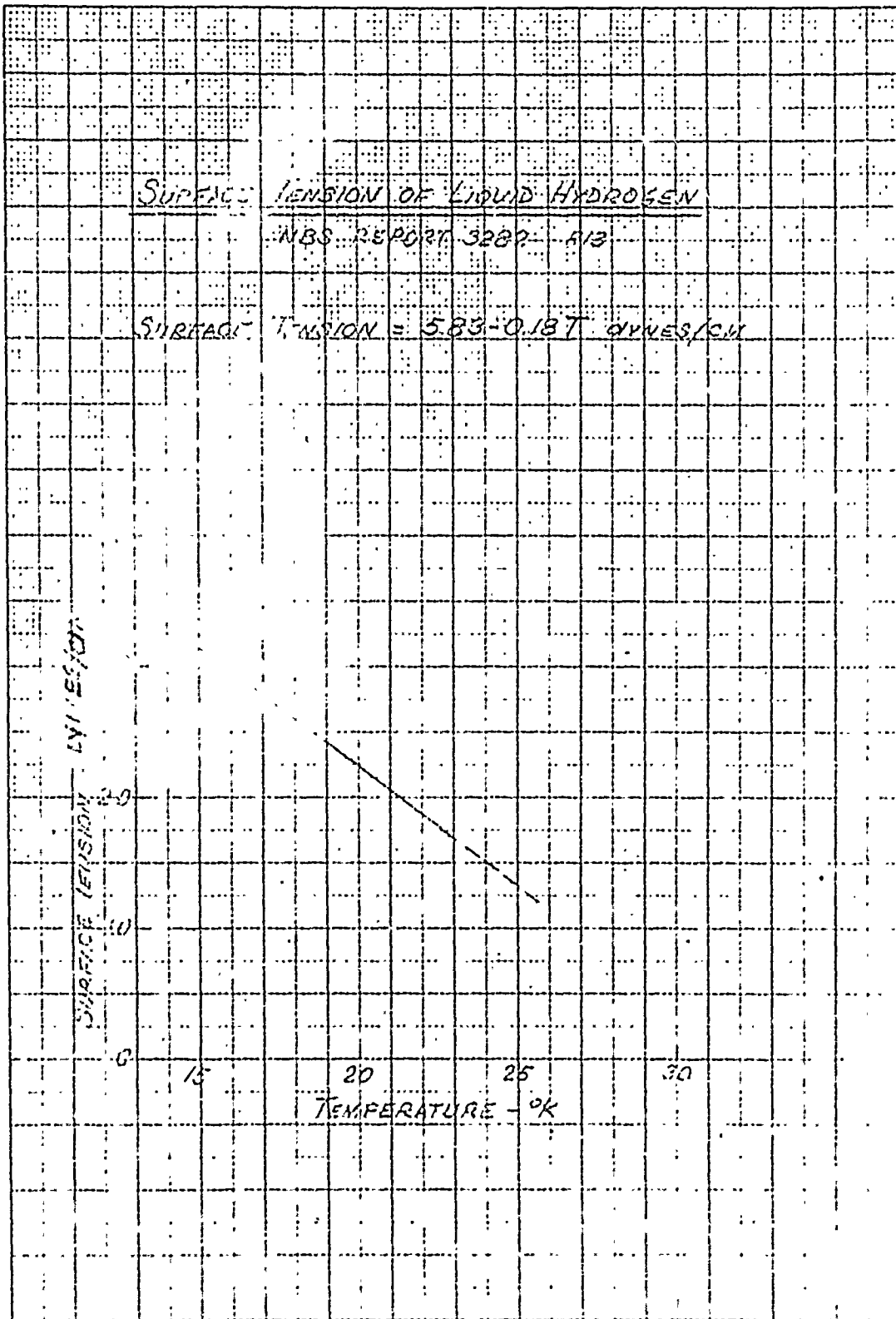
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20

25

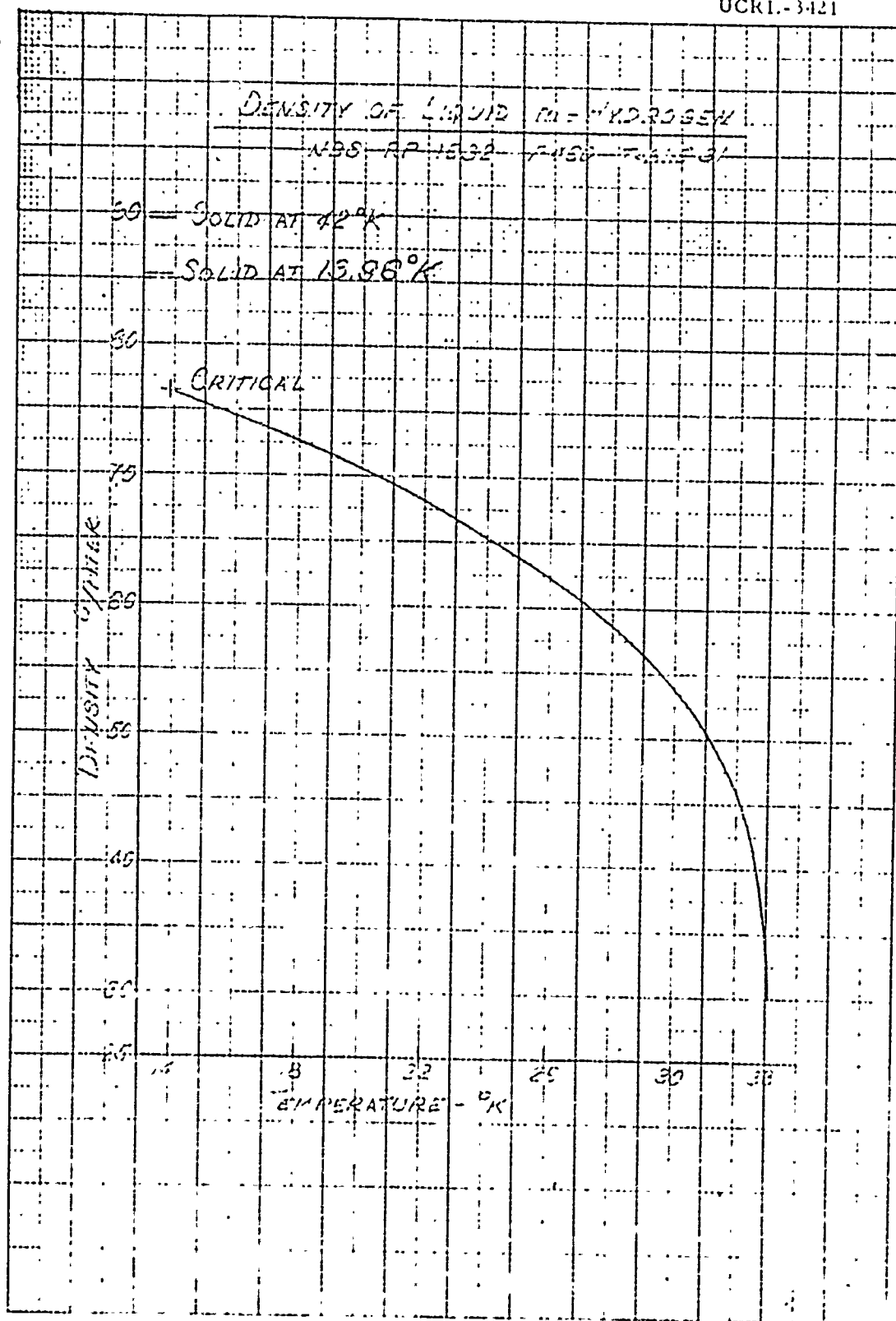
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TEMPERATURE - °K

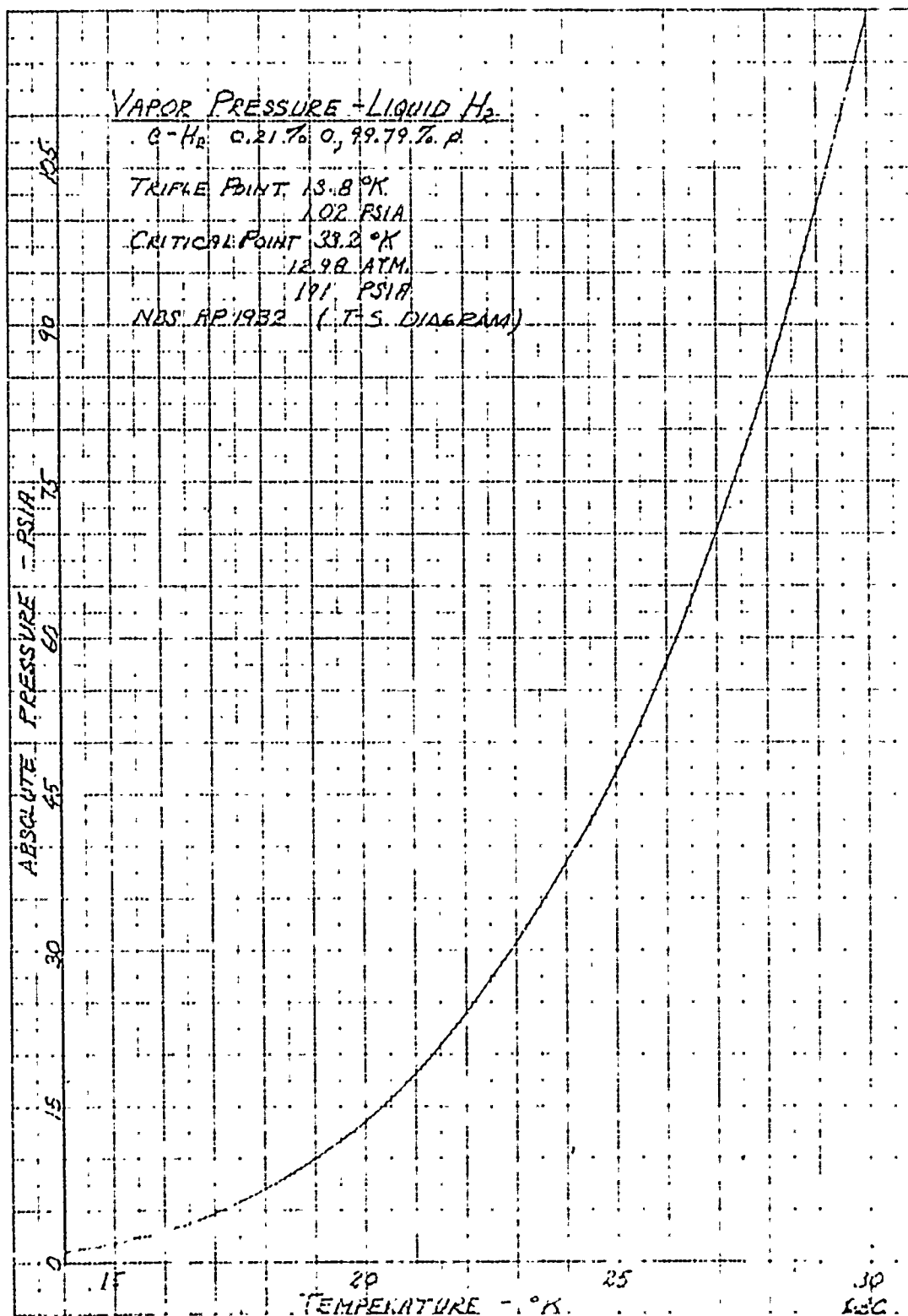


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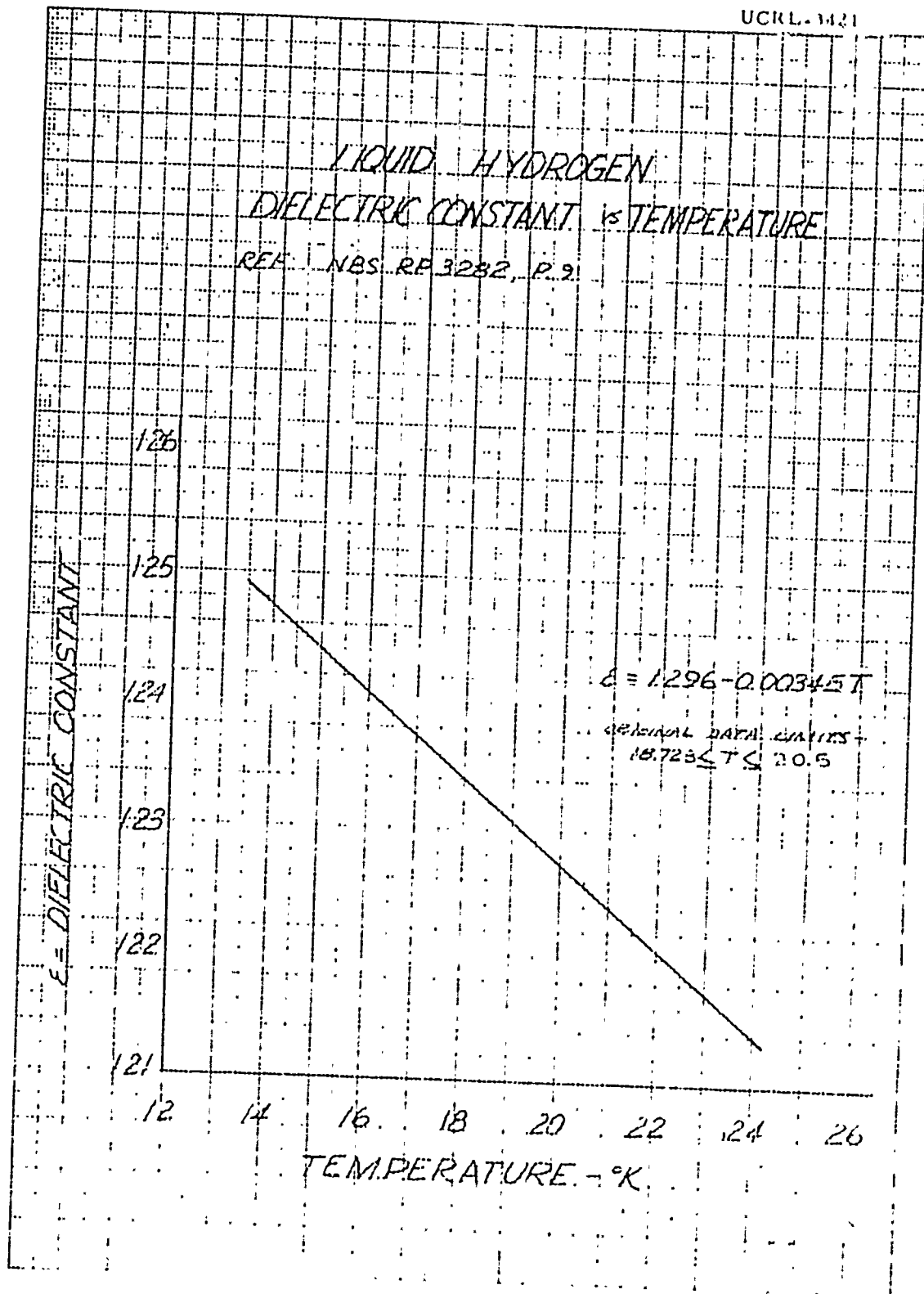
Page 71

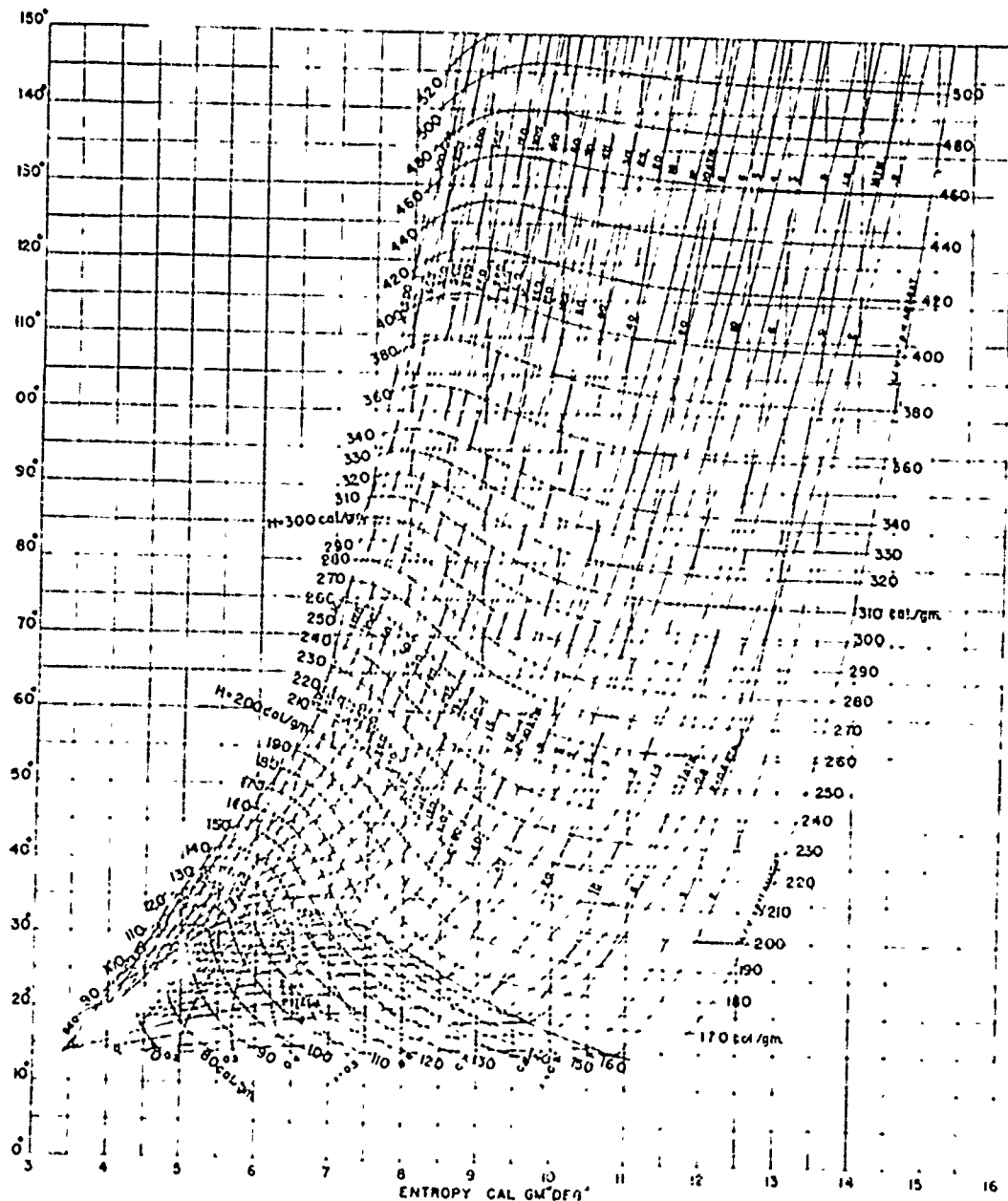
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March 7

1000 0 1000000 1000000

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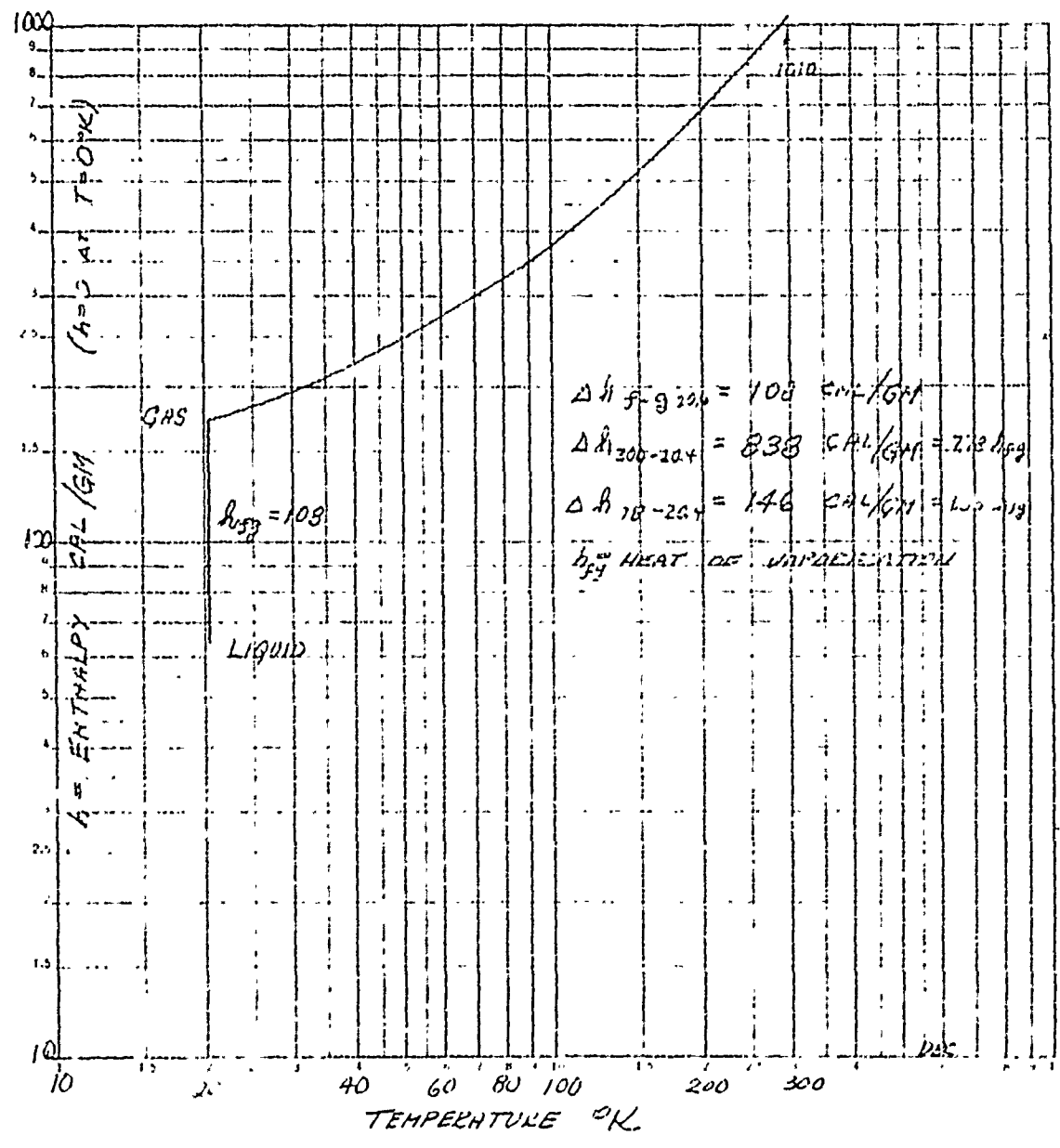
Temperature-entropy diagram for  $H_2$  in the region  $0^\circ$  to  $150^\circ$  K.

REF: NBS RP1932

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# ENTHALPY - HYDROGEN 1 ATM PRESSURE NBS CIRCULAR 564

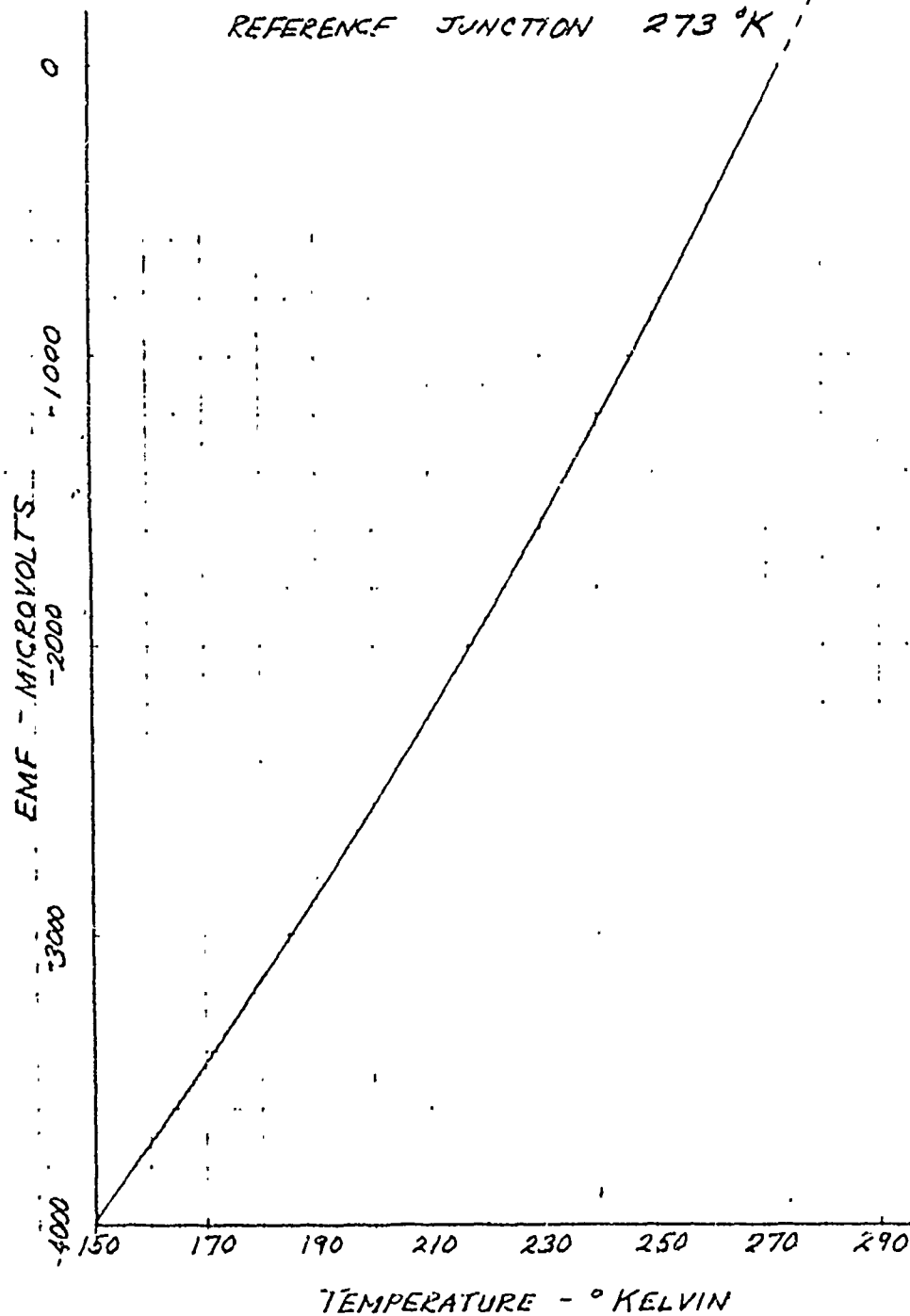


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COPPER - CONSTANTAN THERMOCOUPLES  
150 - 290 °K

REFERENCE JUNCTION 273 °K



147 11/17/51

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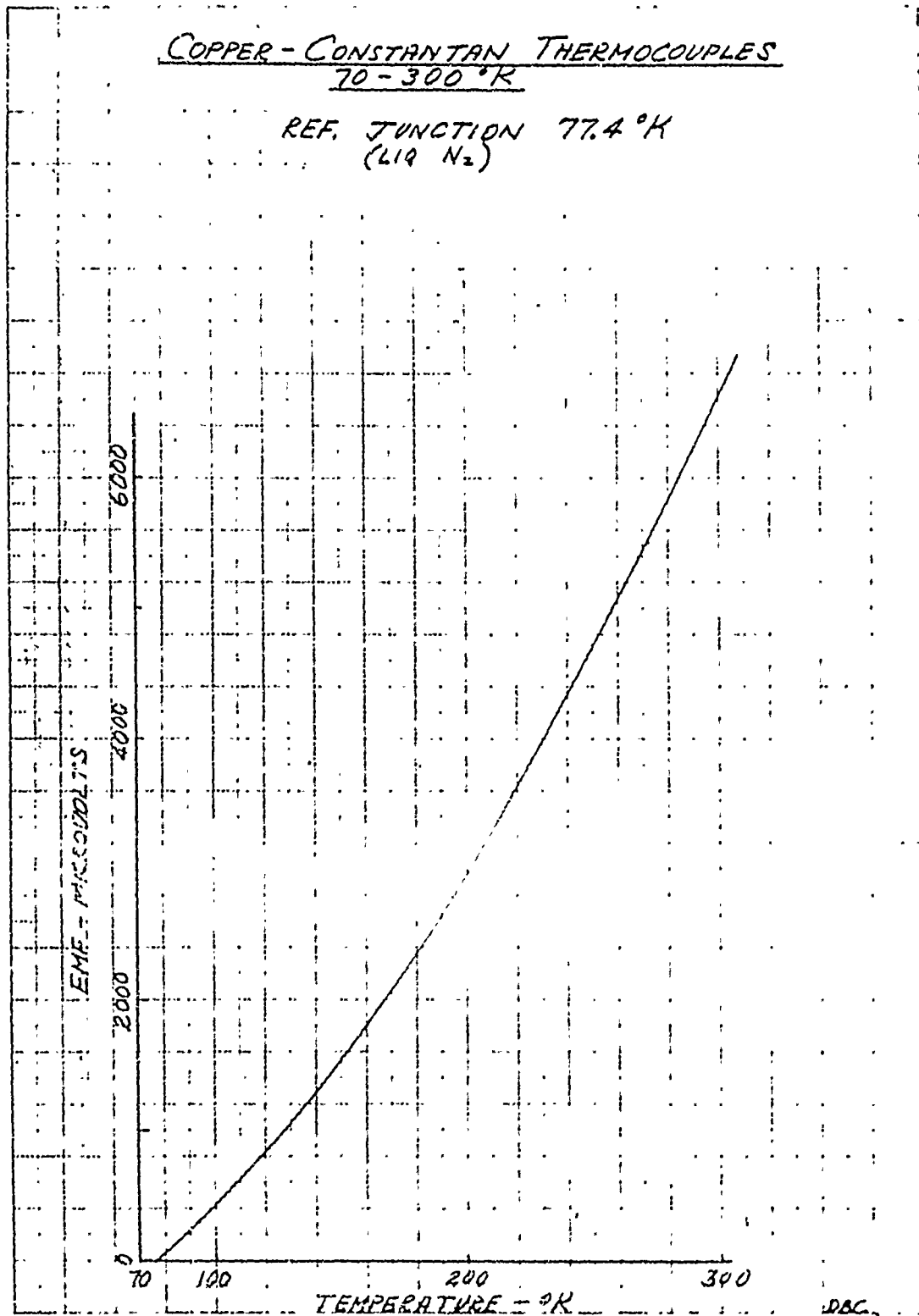
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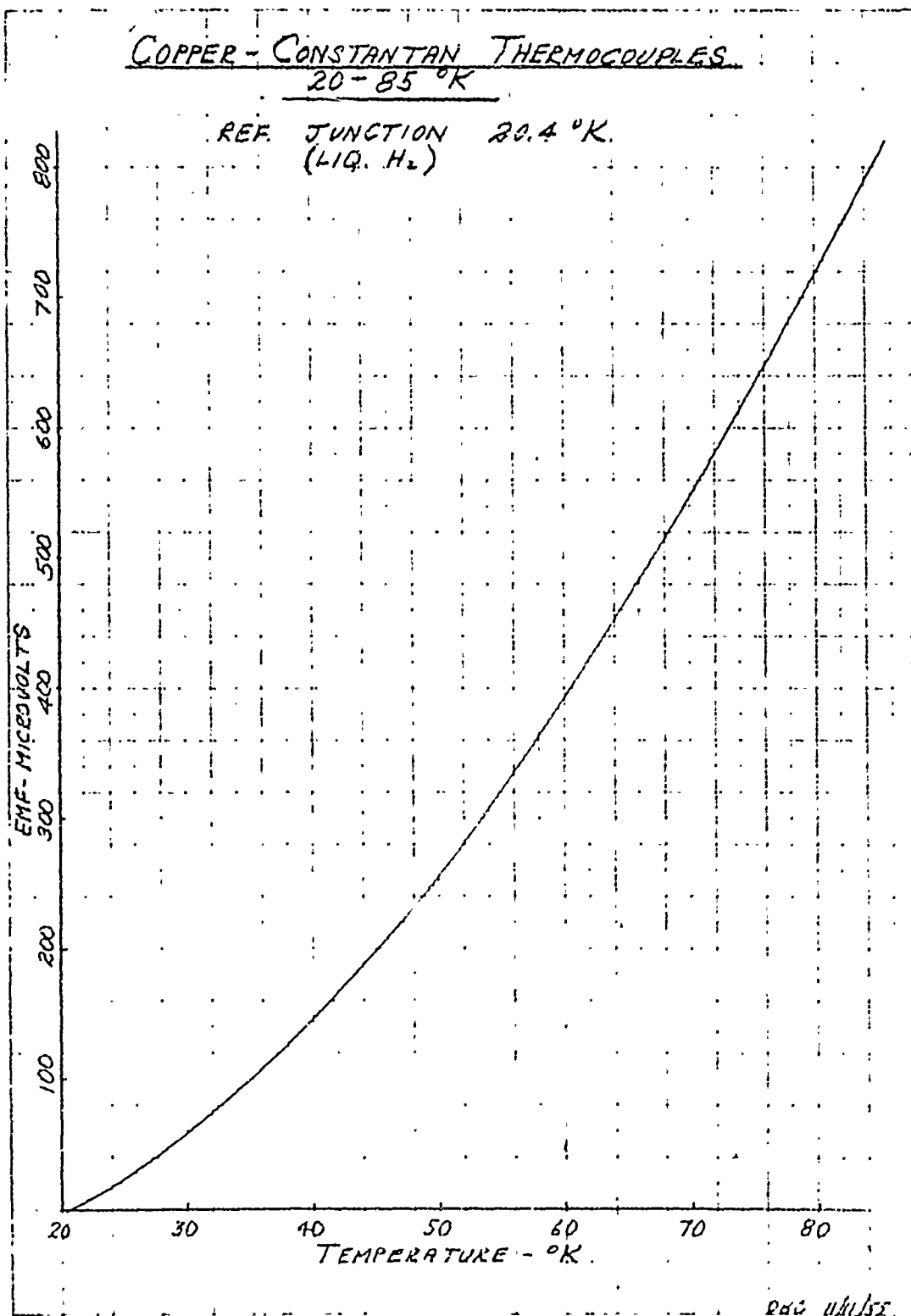
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COPPER - CONSTANTAN THERMOCOUPLES  
70 - 300 °K

REF. JUNCTION 77.4 °K  
(LIQ N<sub>2</sub>)



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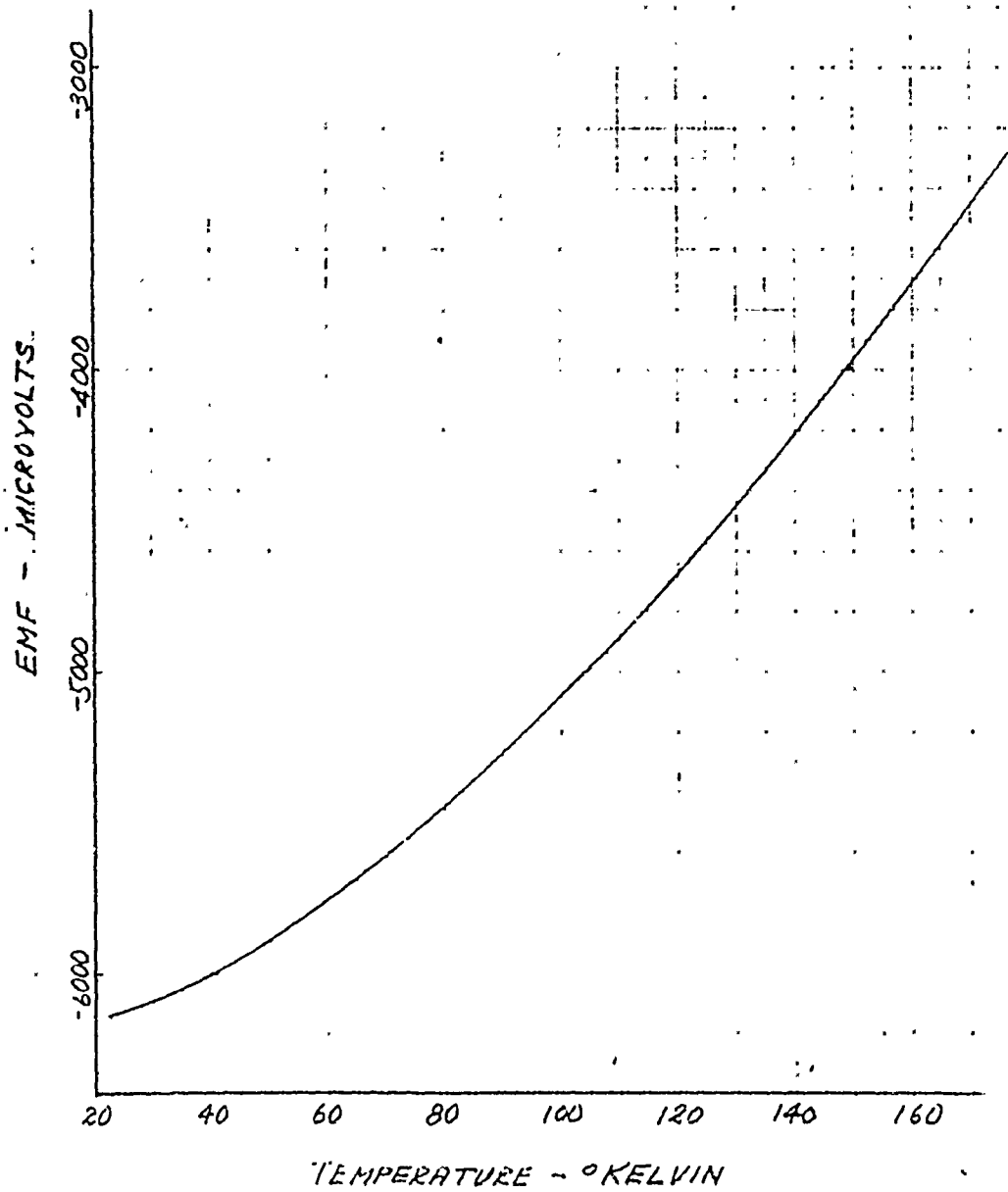


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COPPER - CONSTANTAN THERMOCOUPLES  
20 - 160 °K

REFERENCE JUNCTION 273 °K (0 °C)



DBC 11/10/58

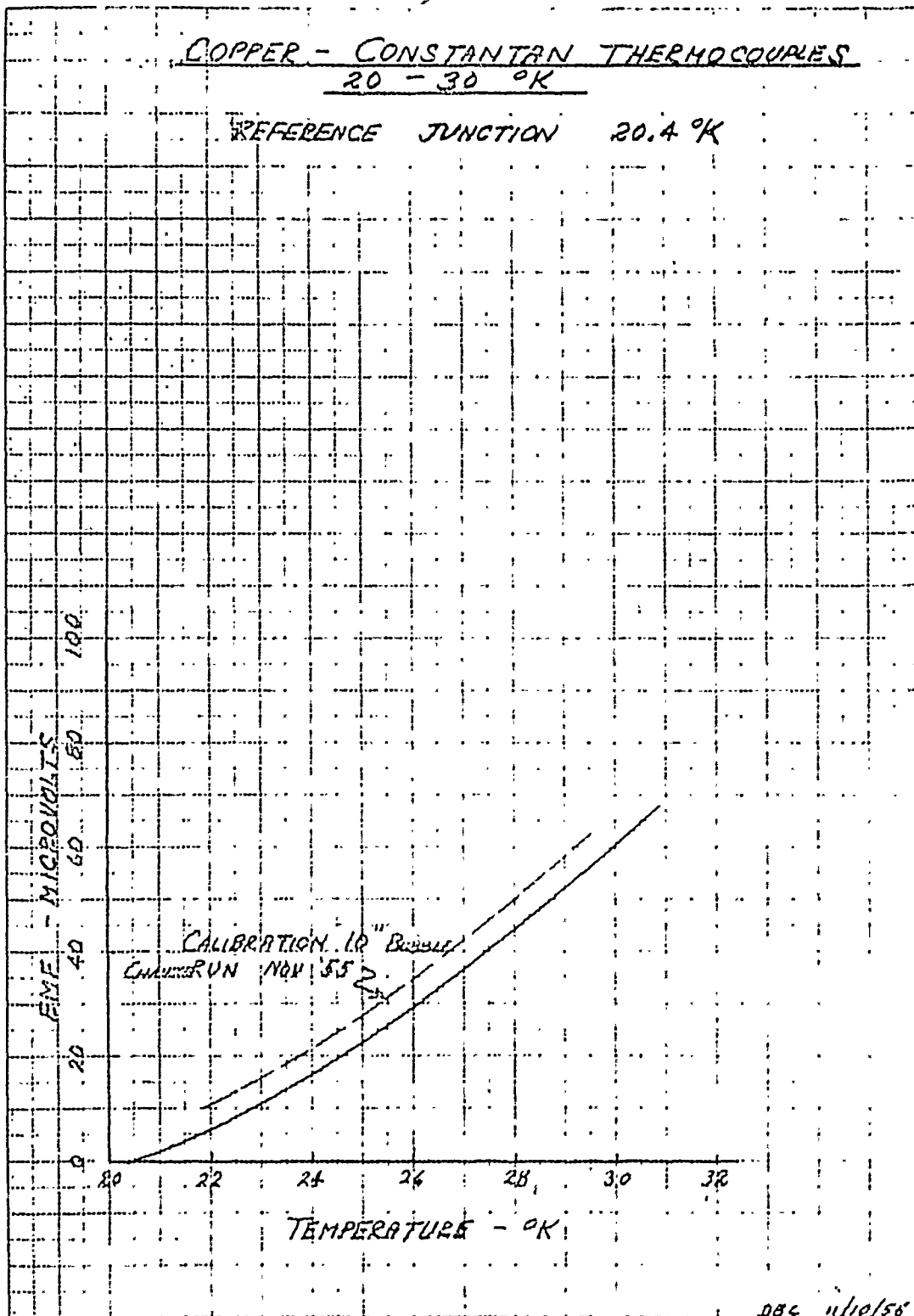
Fig. 178

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Rev. 1-7

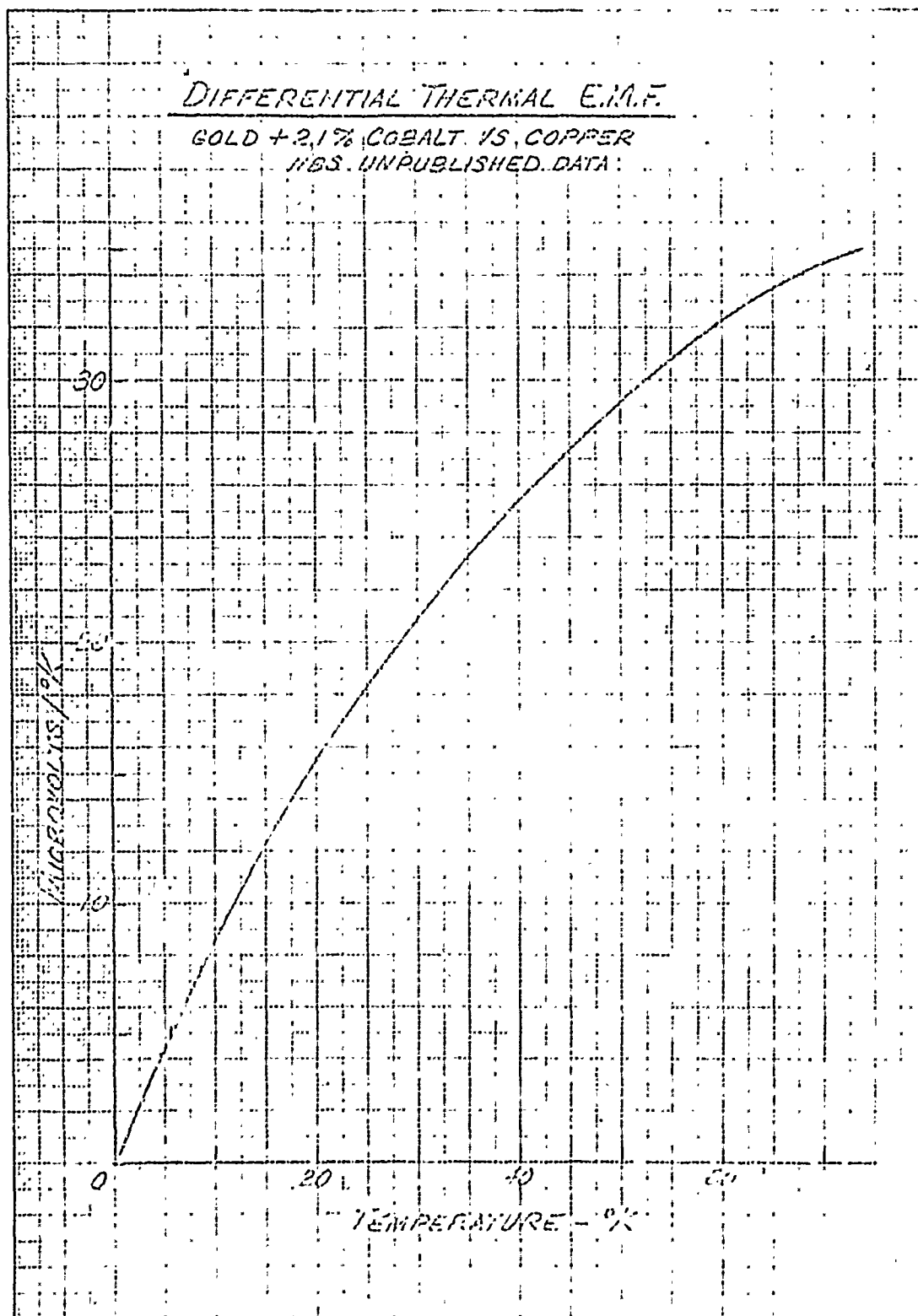
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**TABIE LIV**  
 Heat transfer between parallel surfaces through  
 various types of insulation.\*

Heat transfer is in milliwatts $\text{cm}^{-2}$ through insulation having the indicated boundary temperatures.			
Temperature of warm surface $\rightarrow$ Temperature of cold surface $\rightarrow$	300°K 77°K	300°K 20°K	77°K 20°K
Kind of insulation			
High vacuum $p = 10^{-6}$ mm Hg ( $\text{H}_2$ residual) Emissivity 0.02 at each surface.	0.91	0.92	0.004
Gases at atmospheric pressure (no convection). 15 cm between the warm and cold surfaces			
$\text{H}_2$	19.3 ( $k = 1.30$ )	19.6 ( $k = 1.05$ )	0.8 ( $k = 0.22$ )
He	17.1 ( $k = 1.15$ )	17.7 ( $k = 0.95$ )	1.7 ( $k = 0.45$ )
Air or $\text{N}_2$	2.68 ( $k = 0.18$ )	----	----
Evacuated powder (expanded perlite with density of 5-6 $\text{lbs ft}^{-3}$ ), 15 cm layer.	0.16 ( $\bar{k} = 0.011$ )	0.13 ( $\bar{k} = 0.007$ )	0.007 ( $\bar{k} = 0.002$ )
Gas filled powder (expanded perlite 5 - 6 $\text{lbs ft}^{-3}$ ) 15 cm layer			
He	18.7 ( $\bar{k} = 1.26$ )	18.7 ( $\bar{k} = 1.0 \text{ est.}$ )	2.2 ( $\bar{k} = 0.5$ )
$\text{N}_2$	4.8 ( $\bar{k} = 0.32$ )	----	---
Polystyrene foam ( $2 \text{ lbs ft}^{-3}$ ) 15 cm layer	4.9 ( $\bar{k} = 0.33$ )	5.1 ( $\bar{k} = 0.27$ )	0.57 ( $\bar{k} = 0.15$ )

$\bar{k}$  is the apparent effective mean thermal conductivity for the temperature interval.

$k$  is the actual mean thermal conductivity.

The units for  $k$  and  $\bar{k}$  are milliwatts  $\text{cm}^{-1} \text{ } ^\circ\text{K}^{-1}$ .

\* These computations were made by M. M. Fulk, NBS.

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